ISOS|2023

Simposio Internacional sobre Sistemas de Emisarios 2023

International Symposium on Outfall Systems 2023

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RIACHUELO SYSTEM - OUTFALL LOT 3

ENG. ANDREA CODALLI

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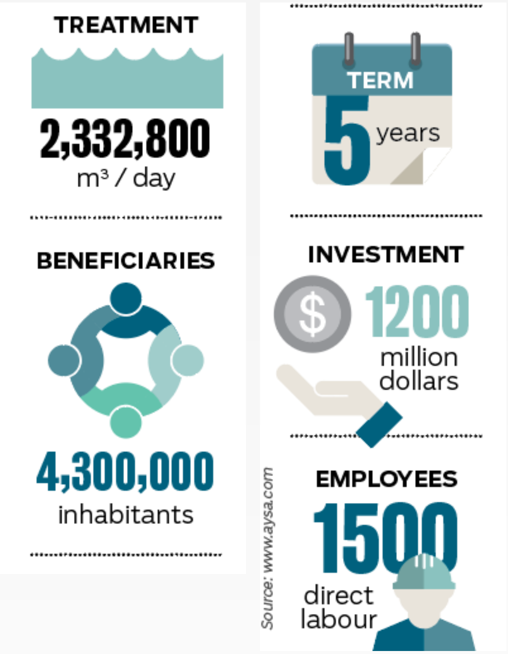
RIACHUELO OUTFALL



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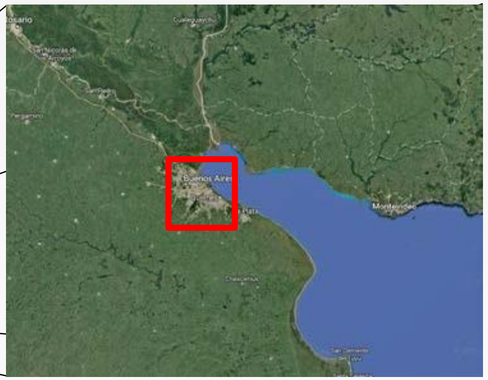
LOCATION



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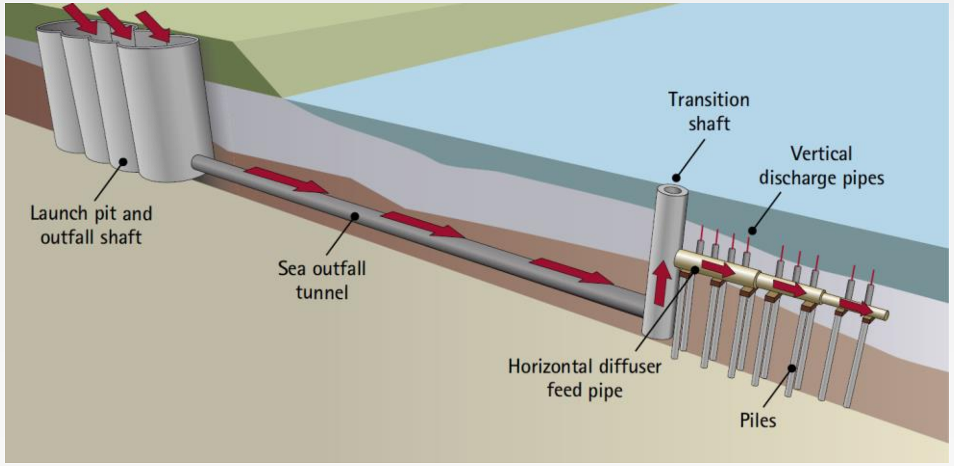
PROJECT – ORIGINAL VS VARIANT

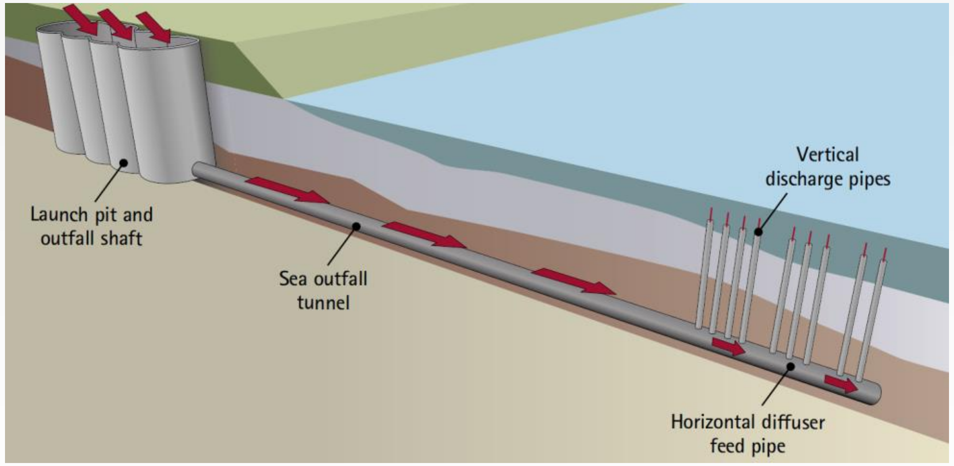
- ✓ Outfall Tunnel (10,5km)
- ✓ Offshore Transition Shaft
- ✓ Diffuser section:
  - Deep foundations (35m)
  - Pipes (3,8/2,8/1,7m)
  - Risers (≈5m each)

Sea Outfall
Initial Solution

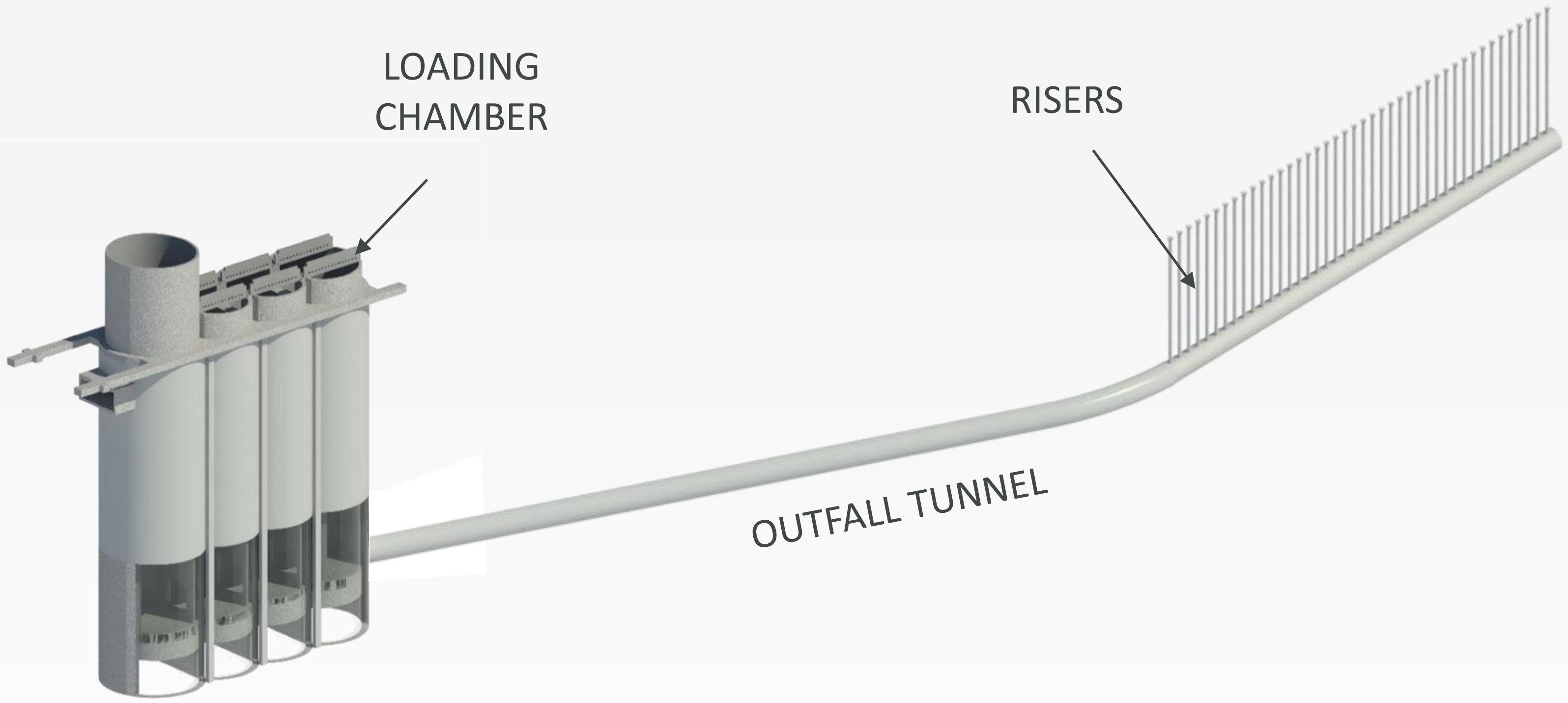


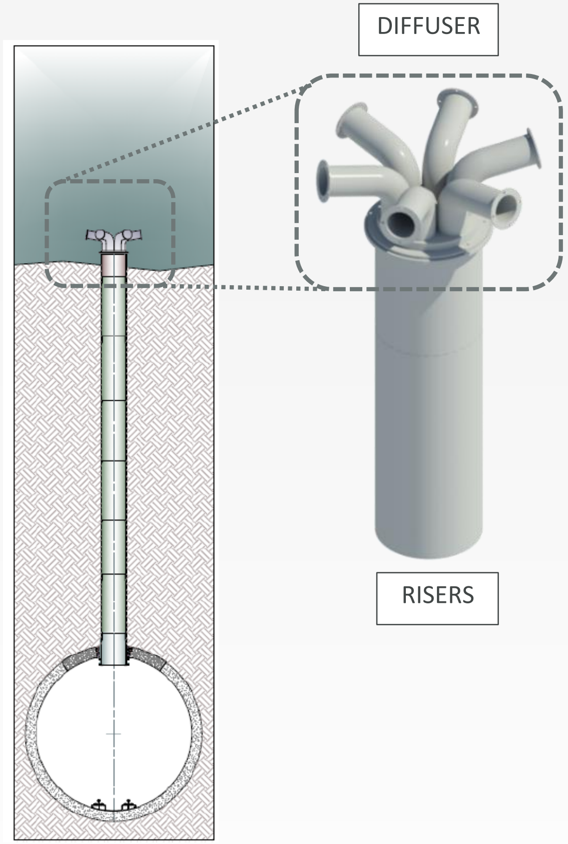
- ✓ Outfall Tunnel (10,5km)
- ✓ Diffuser section:
  - Diffuser Tunnel (1,5km)
  - Risers (≈35m each)

Sea Outfall
Alternative Solution
(Riser Concept)



PROJECT – OVERALL CONCEPT





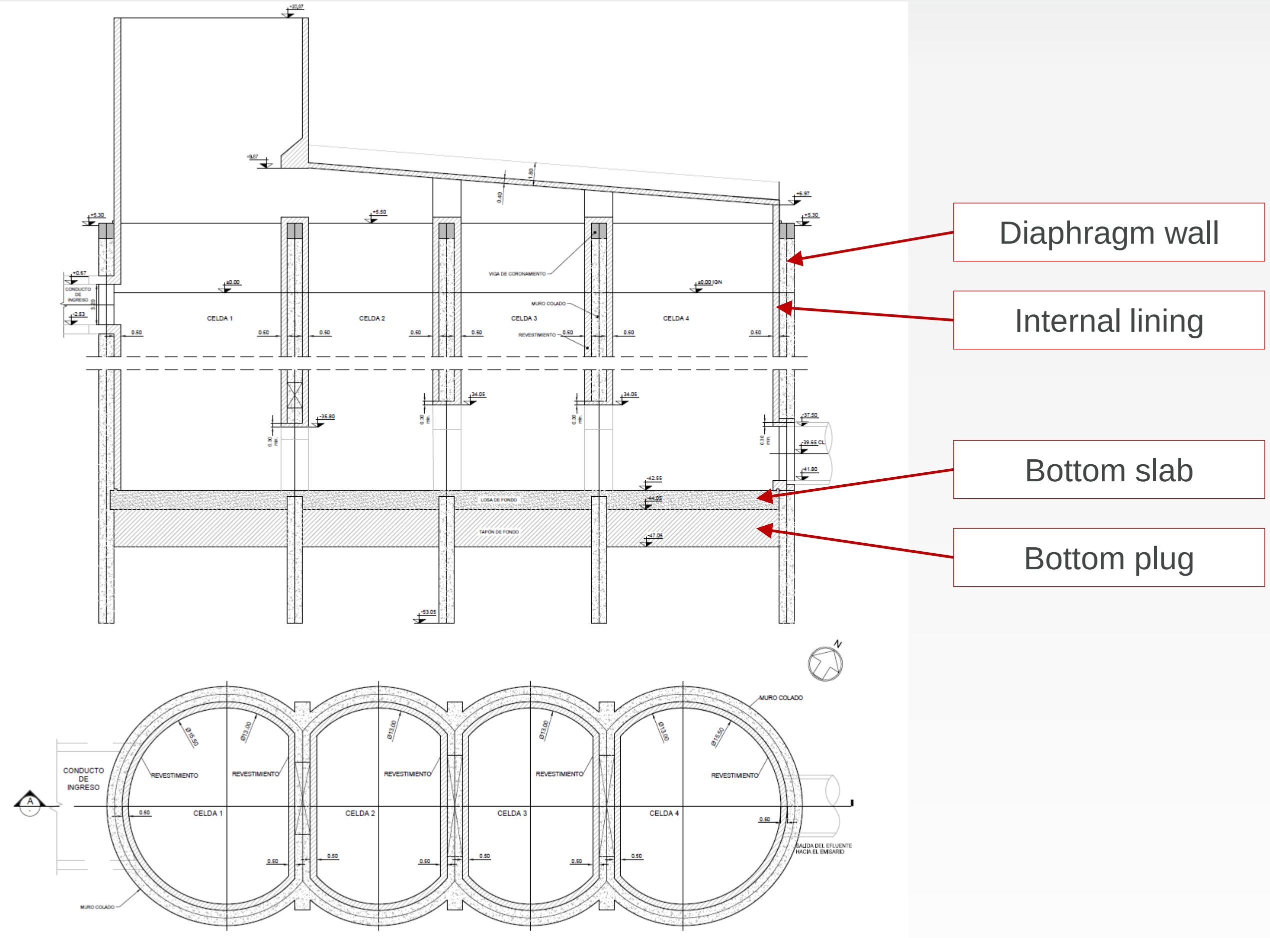
LOADING CHAMBER – GENERAL DESIGN

Design:

- Internal cell diameter: 15,50 m
- Diaphragm Wall thk: 1,20 m
- Bottom plug thk: 3,00 m
- Bottom slab thk: 1,50 m
- Internal lining thk: 0,50 m

Construction sequence:

1. Diaphragm walls construction
2. Excavation under wáter
3. Bottom plug
4. Unwatering of loading chamber
5. Bottom slab
6. Internal lining



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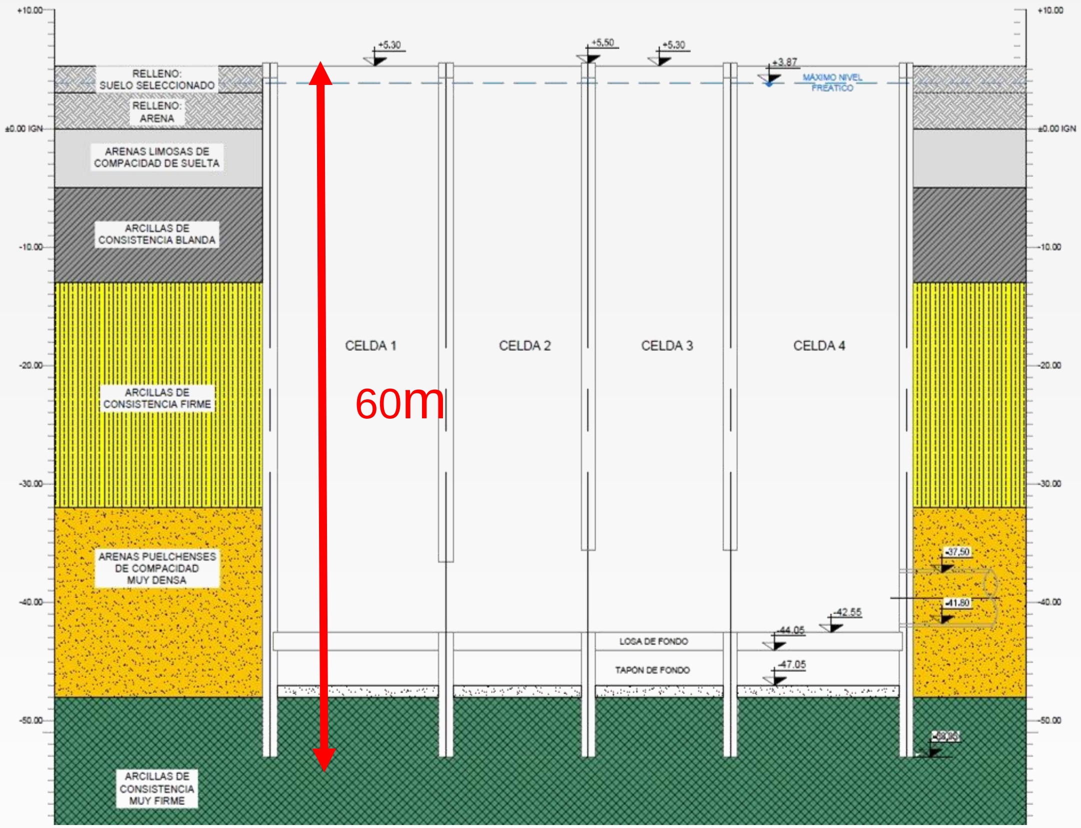
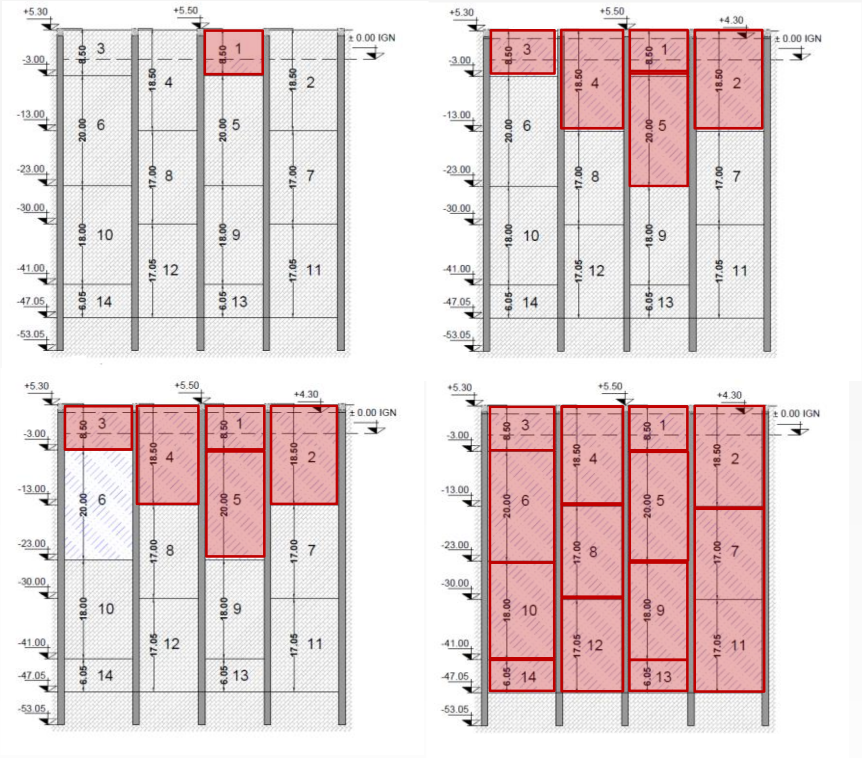
LOADING CHAMBER – DIAPHRAGM WALLS

- Diaphragm walls
- 60 m depth and 1,20 m thick
- Multiple panels (600 m3/panel)
- Total volume: 12’400 m3



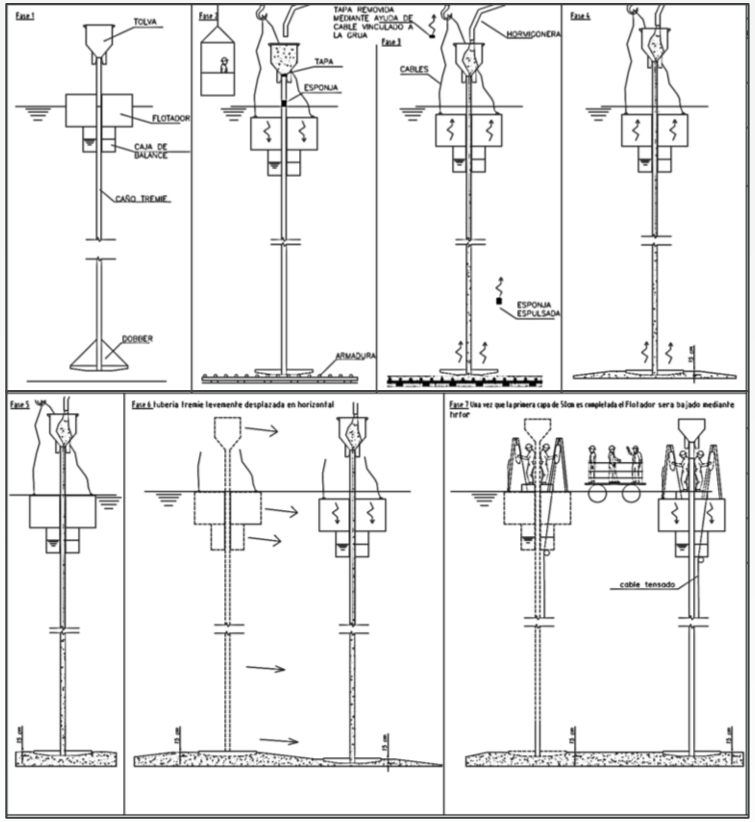
LOADING CHAMBER – EXCAVATION

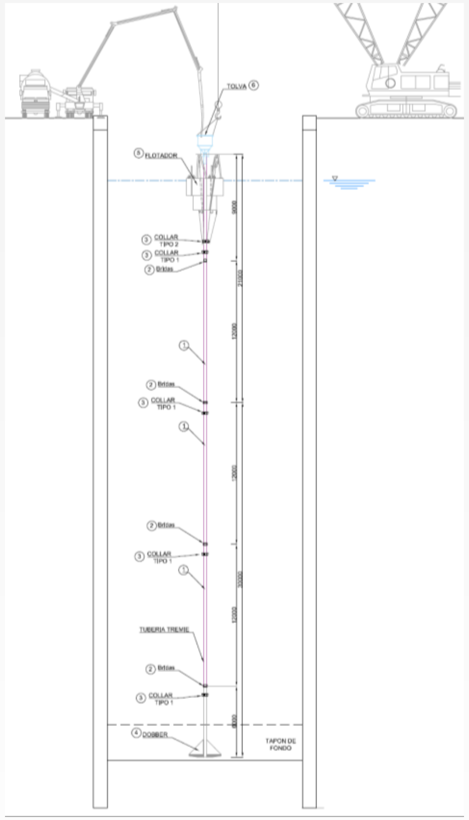
- Stepped excavation (backhoe / clamshell / Dragflow) with defined maximum difference between cells ground level according to the cast wall design
- Underwater inspection and cleaning with divers



LOADING CHAMBER – BOTTOM PLUG

- Concrete bottom plug pour with a Tremie – Dobber system – 3,00m thickness





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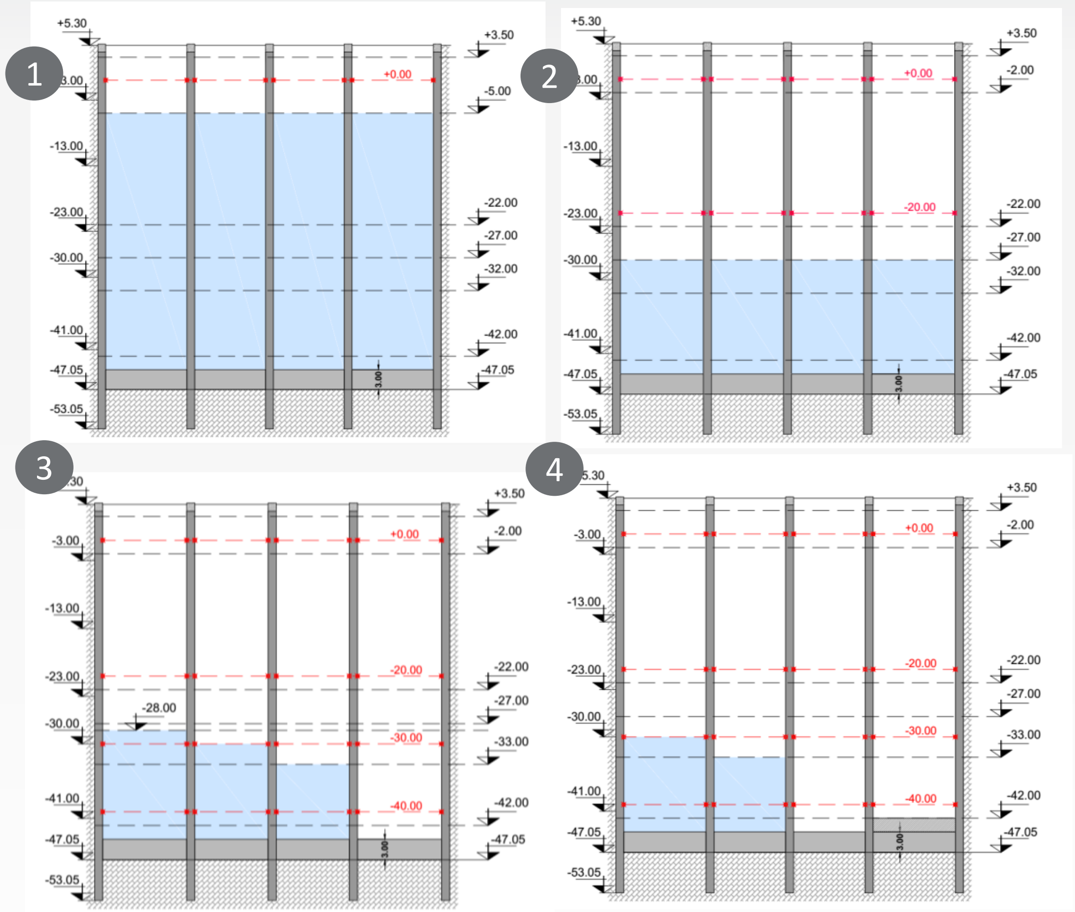
LOADING CHAMBER – UNWATERING OF THE LOADING CHAMBER



- Unwatering sequence
- Construction of bottom slab

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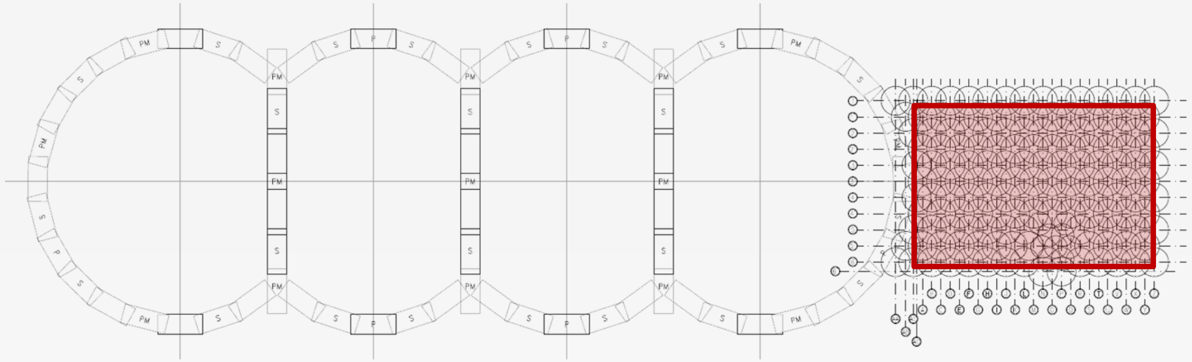
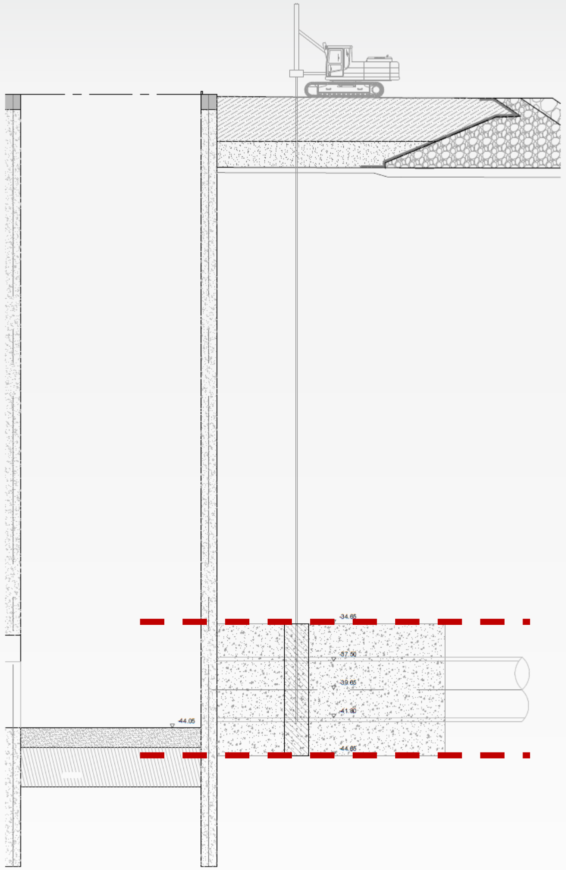
LOADING CHAMBER – GROUND IMPROVEMENT

- Jet grouting columnas outside the loading chamber 158 columns – 1,80m (40-50 m depth)

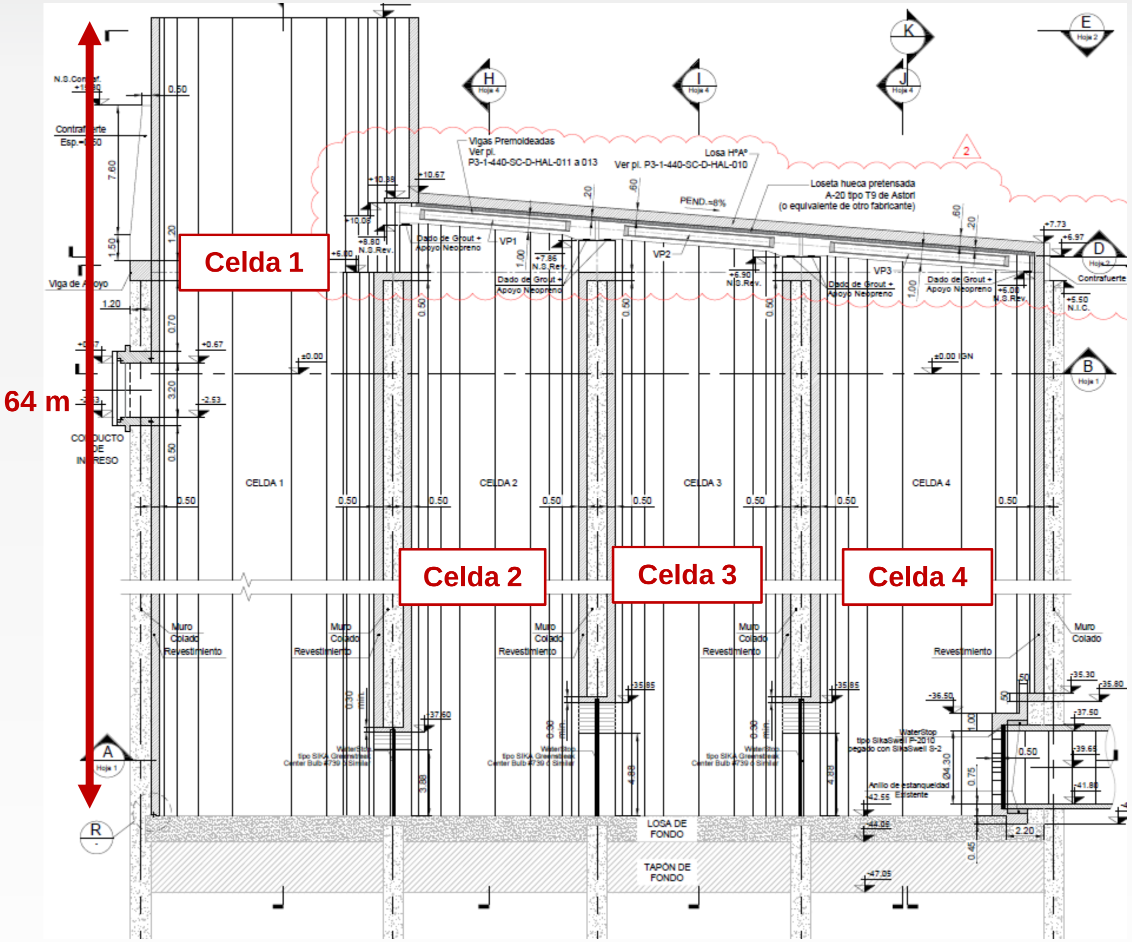




- Secundary injection from the shaft in n.3 different

LOADING CHAMBER – FINAL INTERNAL LINING

- Thickness 0,50 m
- Sliding formwork



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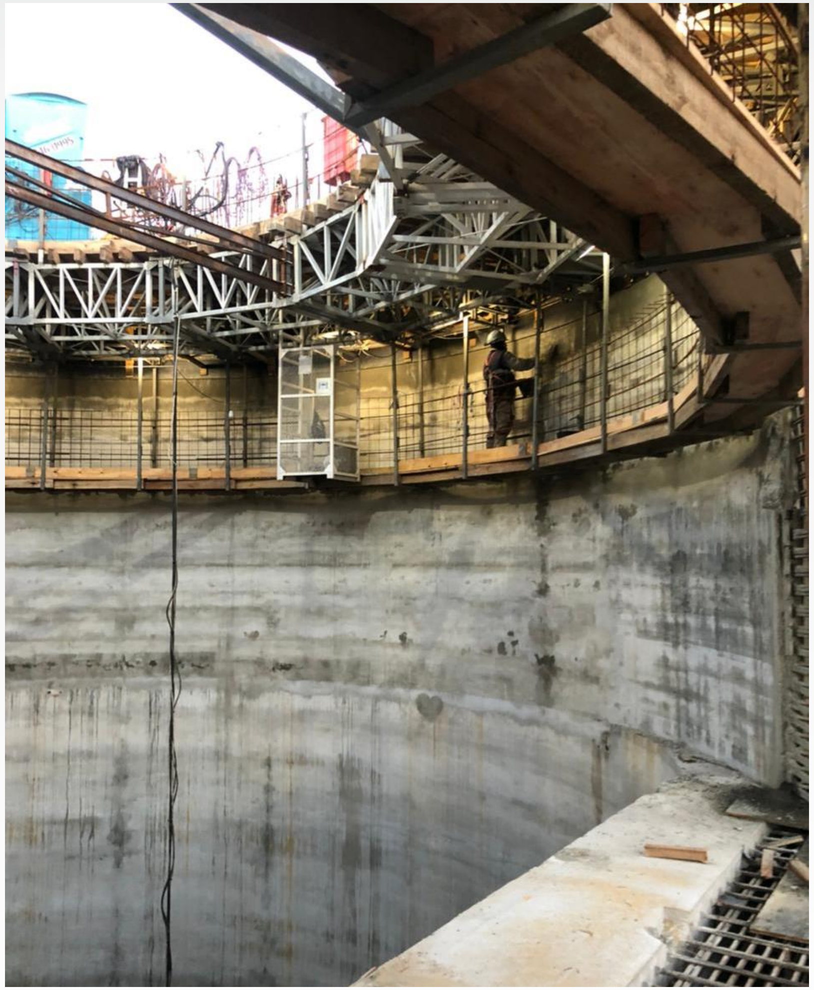
LOADING CHAMBER



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LOADING CHAMBER

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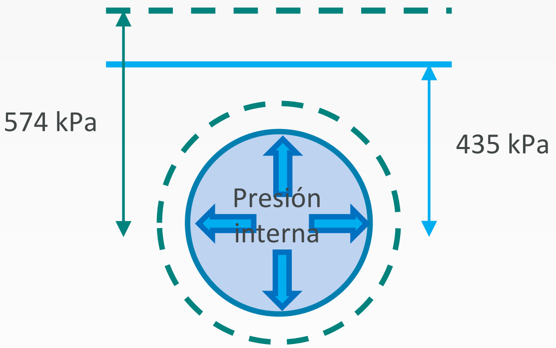
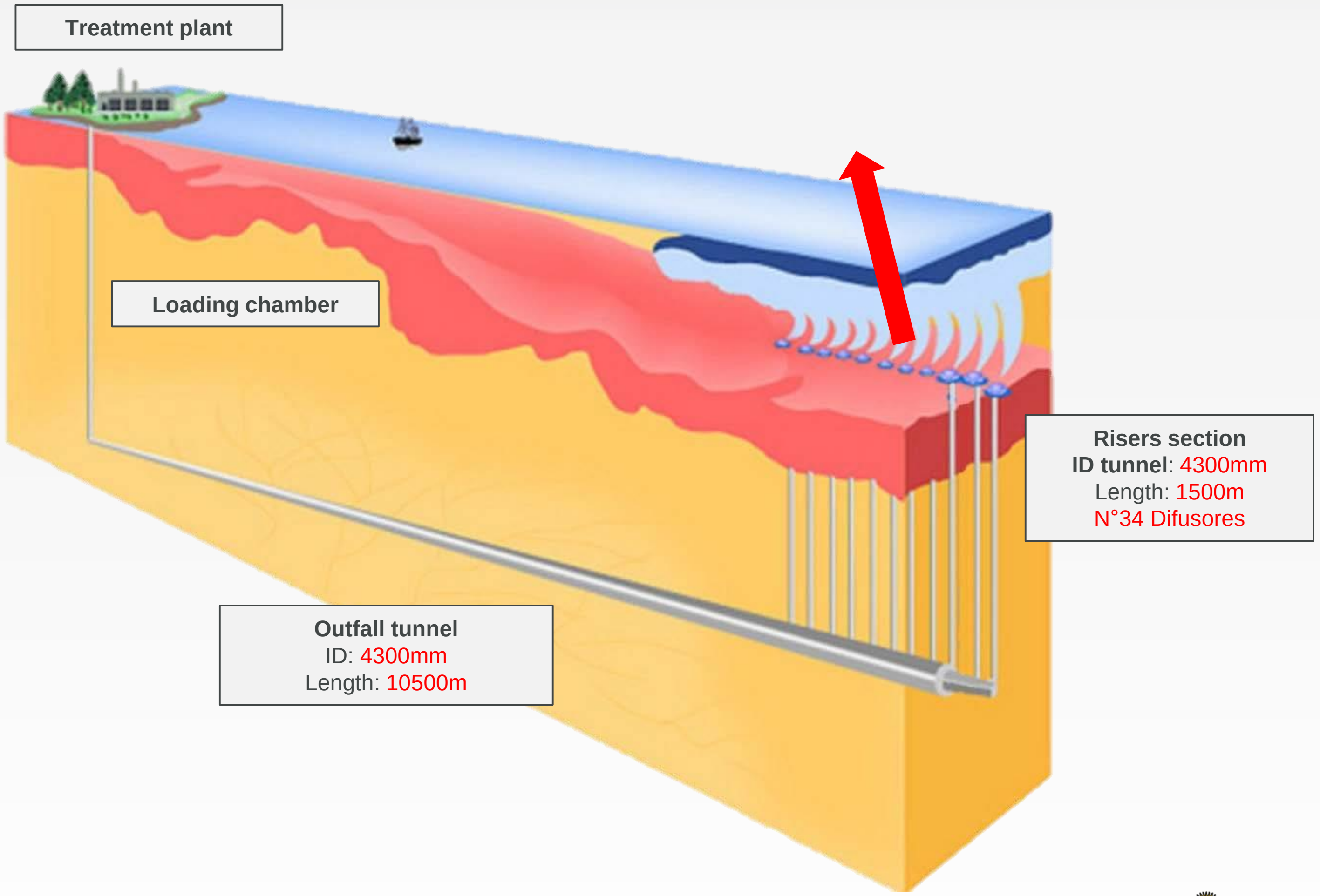
OUTFALL TUNNEL – GENERAL DESIGN

- Design flow = 27 m^3/s
- Roughness: 3 mm (ks)
- External pressure: 43.5 mca
- Internal pressure: 57.4 mca
- **Differential pressure ≈ 13.9 mca**





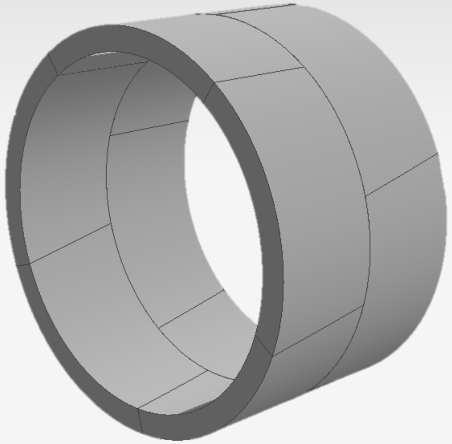
OUTFALL TUNNEL – DESIGN

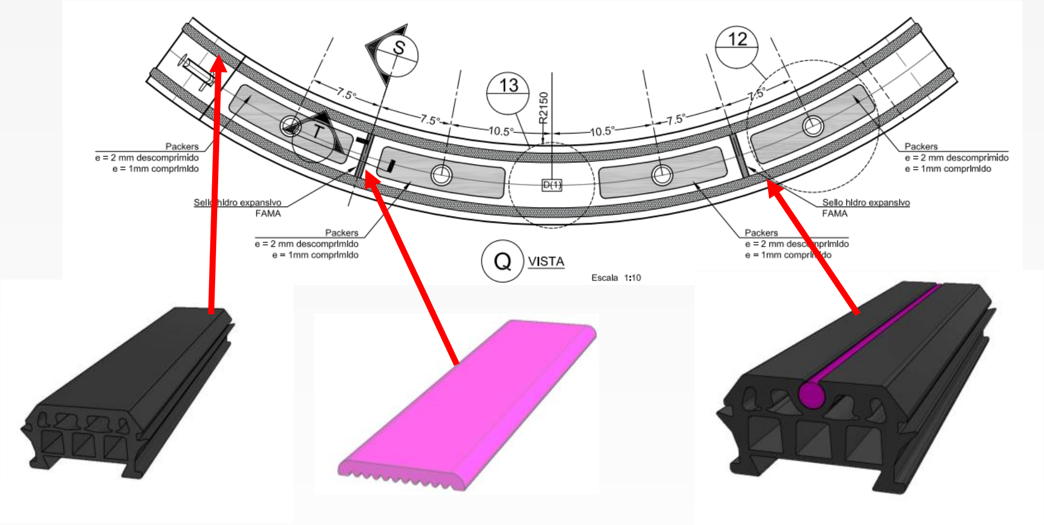
Etructural test during design stage:

- Step 1 = 0,65bar: Exceptional load condition
- Step 2 = 1,00bar: Exceptional load condition x 1,6 (FS)

OUTFALL TUNNEL – RING DESIGN

Ring type:	Universal (5 segments)
OD / ID	4900 mm / 4300 mm
Thickness	300 mm
Length	1400 mm
Taper	± 7 mm
Circunferential joint	4 conectors
Longitudinal joint	2 SS bolts–A4-80L
Gaskets	Doble anchored gaskets UG018A (Internal) UG037A (External) +hydrophilic profile
Concrete	H50





OUTFALL TUNNEL – RING DESIGN

GASKETS

LONG. CONECTOR SOCKET

PACKER

HYDROPHILIC PROFILE

RADIAL BOLT SOCKET

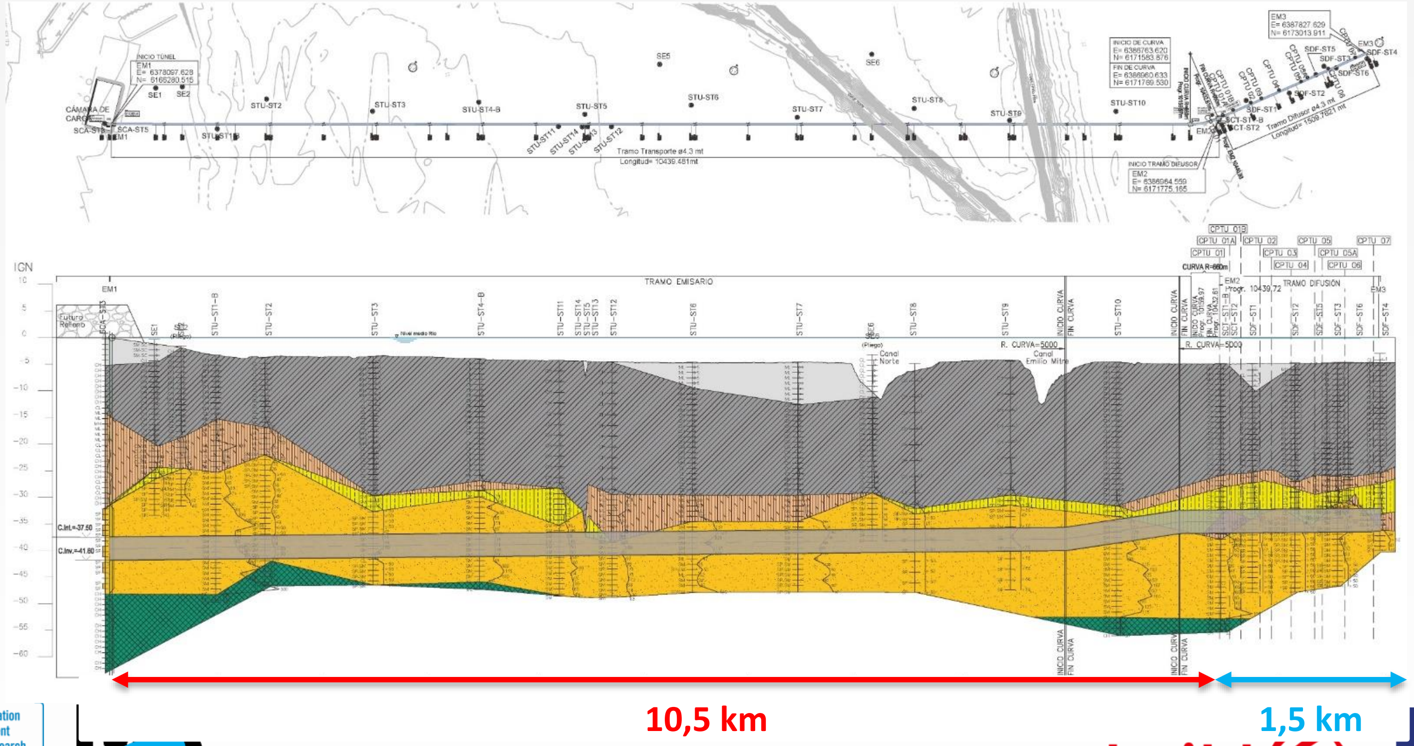
GUIDE ROD

HYDROPHILIC PROFILE

OUTFALL TUNNEL – GEOLOGICAL PROFILE

- Tunnel length: 10439 m
- Diffusor section length: 1510 m
- Abandonment of TBM: 20 m
- Mining in sand (soft soil)

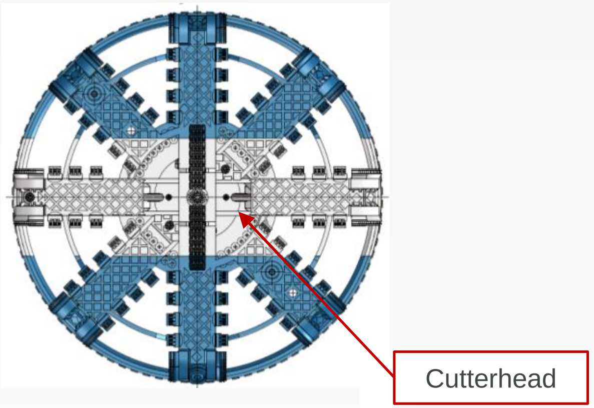
TBM EPB ø4,30m
Up To 6 bar



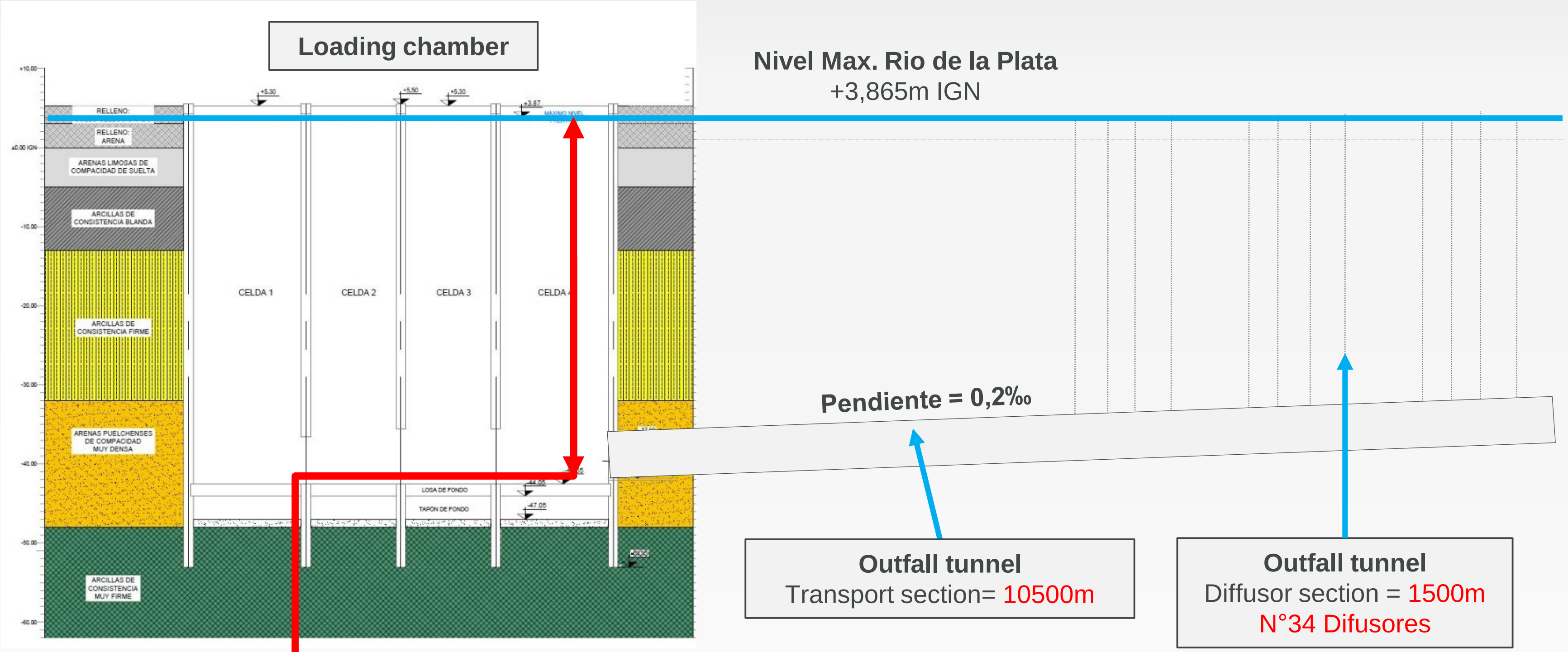
- Rellenos
- Arenas limosas de compacidad suelta
- Arcillas de consistencia blanda
- Arcillas de consistencia firme
- Arenas Puelchenses de compacidad muy densa
- Arcillas de consistencia muy firme

OUTFALL TUNNEL – TBM DESIGN

- TBM: EPB - HK
- Working pressure: 6 bar
- Excavation diameter: 5200mm
- TBM length: 220m



OUTFALL TUNNEL – TBM DESIGN



Max. Rio level = 3,865m IGN

Min. springline tunnel = -39,65m IGN

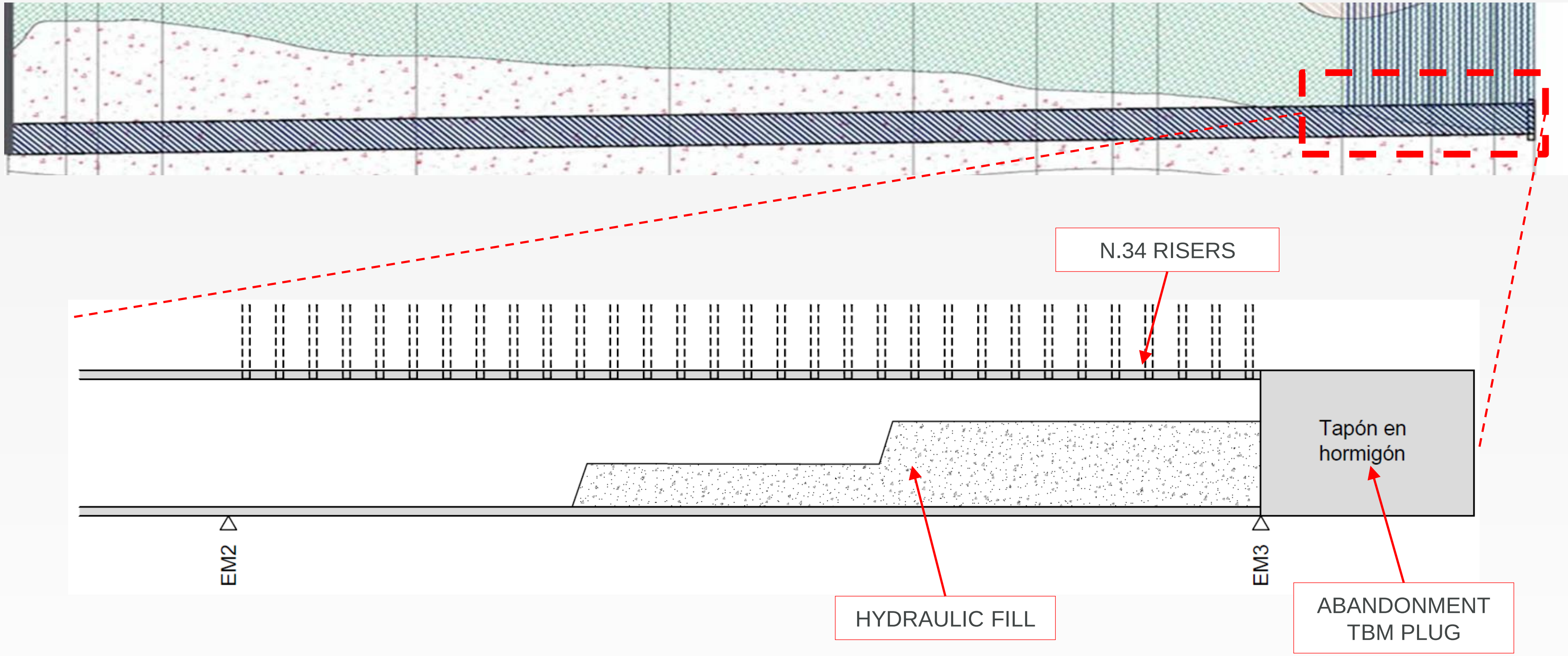
External pressure in the construction stage = 4,35 bar

Operacional pressure of TBM above 3 bar for the entire length of the túnel

OUTFALL TUNNEL

OUTFALL TUNNEL – DIFFUSOR SECTION DESIGN

1. Especial rings installation
2. TBM Abandonment
3. Risers Jacking
4. Execution of hydraulic fill



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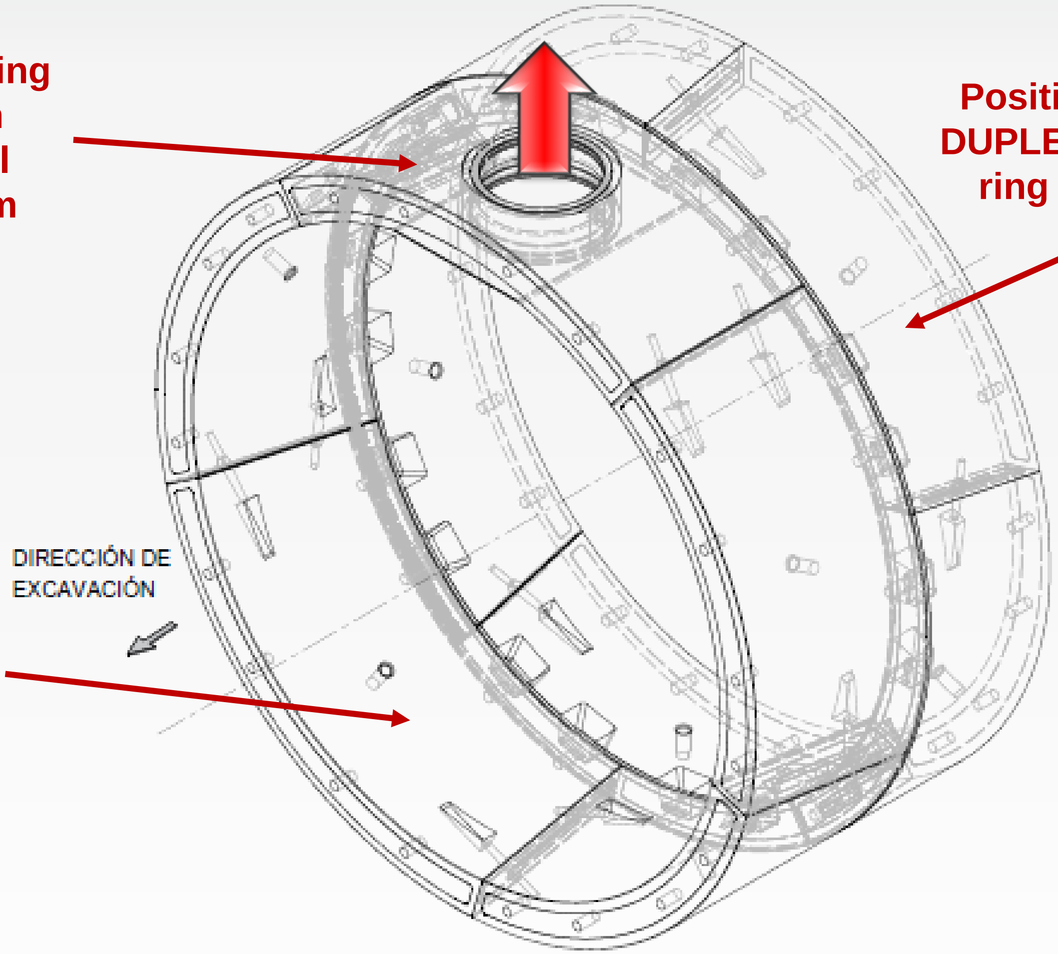
OUTFALL TUNNEL – ESPECIAL RINGS DESIGN

Keyston launching segment with DUPLEX Steel sealing system

Positioning ring with DUPLEX Steel plate for ring roll correction



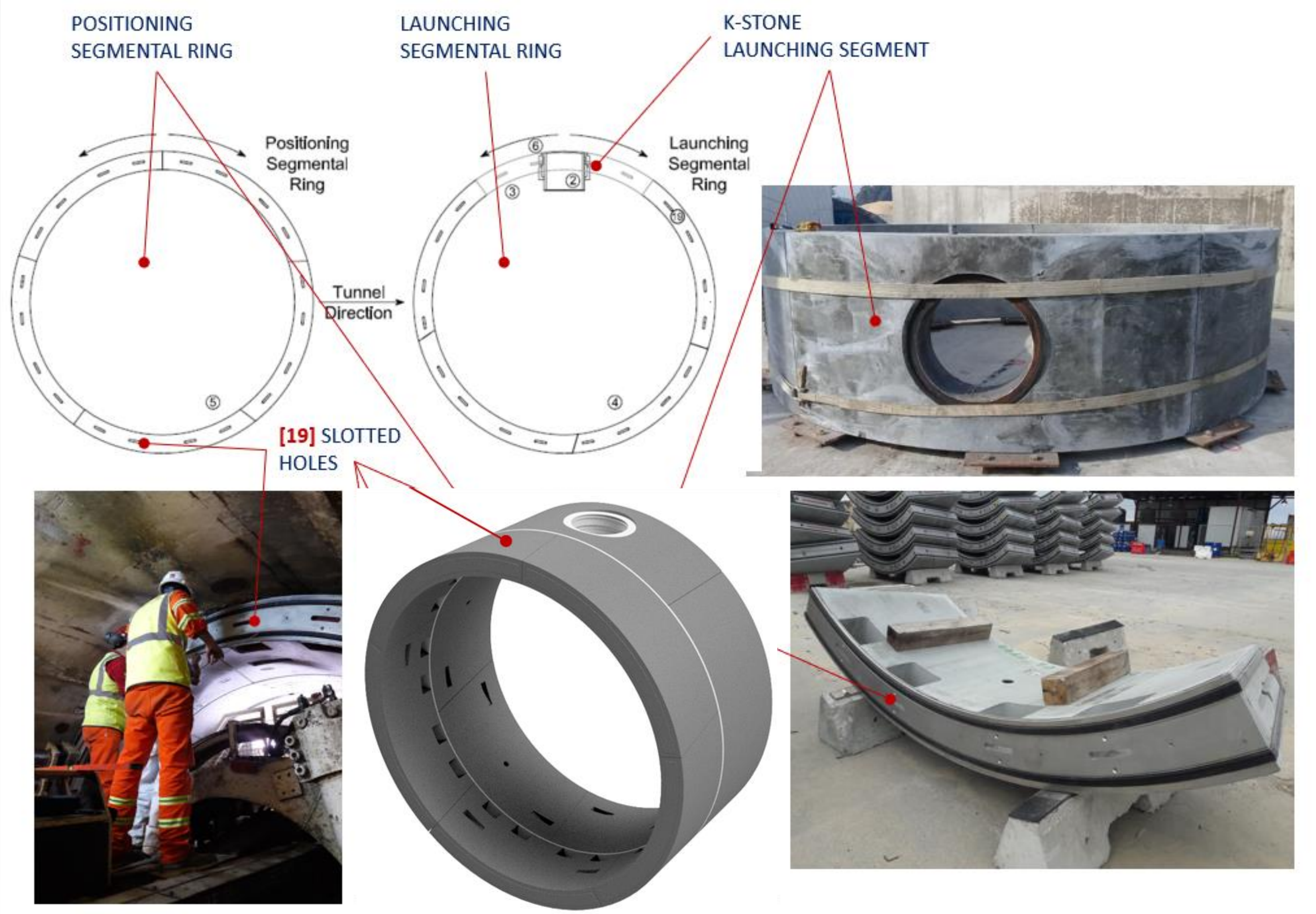
Launching ring

- **No. 34 couples of especial rings**
- **No.1 for each Riser**

OUTFALL TUNNEL – ESPECIAL RINGS

Details of the Riser Concept – Positioning ring

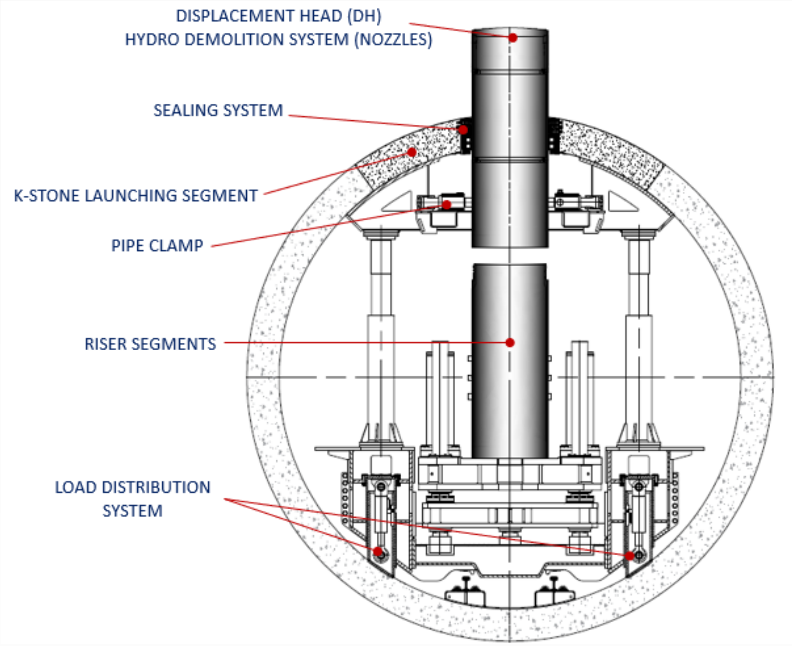
- ✓ Positioning duplex steel plate



OUTFALL TUNNEL – ESPECIAL RINGS

Details of the Riser Concept – Launching ring

- ✓ Keystone Launching Segment
- ✓ Duplex Sealing System
- ✓ Displacement Head



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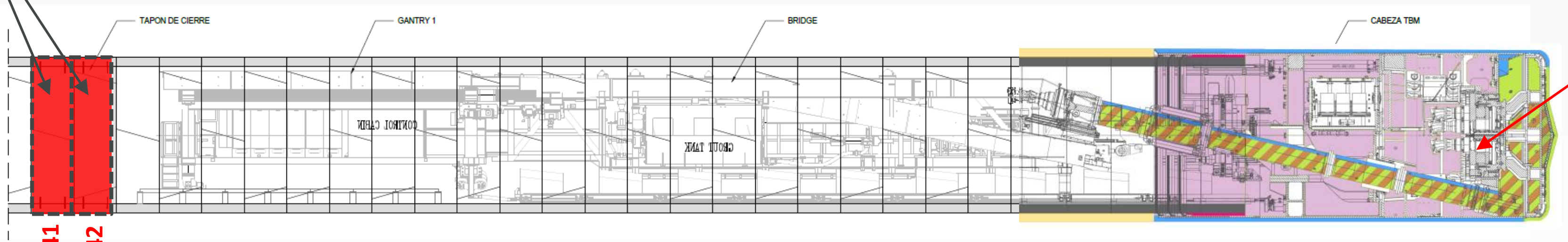
OUTFALL TUNNEL – ESPECIAL RINGS

OUTFALL TUNNEL – TBM ABANDONMENT

TBM Abandonment and execution of final plug

- ✓ TBM encapsulation
- ✓ Filling of excavation chamber
- ✓ Pouring of front, middle and tail skin shields
- ✓ Execution of final plug

TAPÓN DE CIERRE



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ENCAPSULATION OF TBM AND FILLING OF CHAMBER AND SCREW CONVEYOR

OUTFALL TUNNEL – HYDRAULIC CONCRETE FILL

- ✓ Hydraulic section reduction with concrete in order to guarantee self-cleaning velocity (>0,6 m/s)
- ✓ Self-leveling concrete without reinforcement

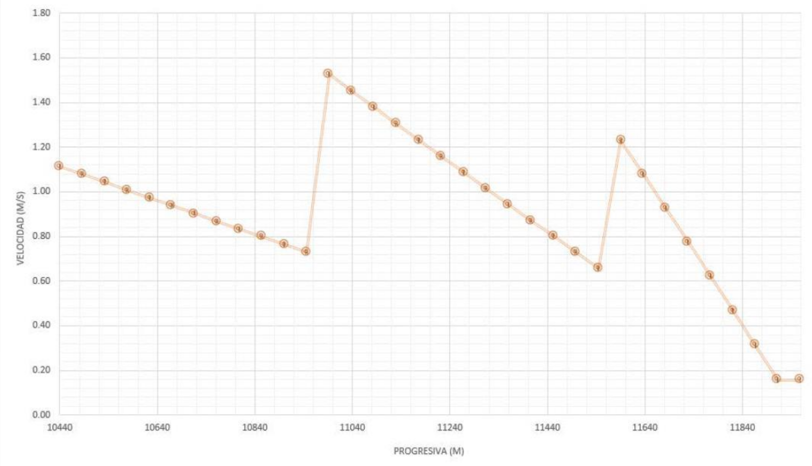
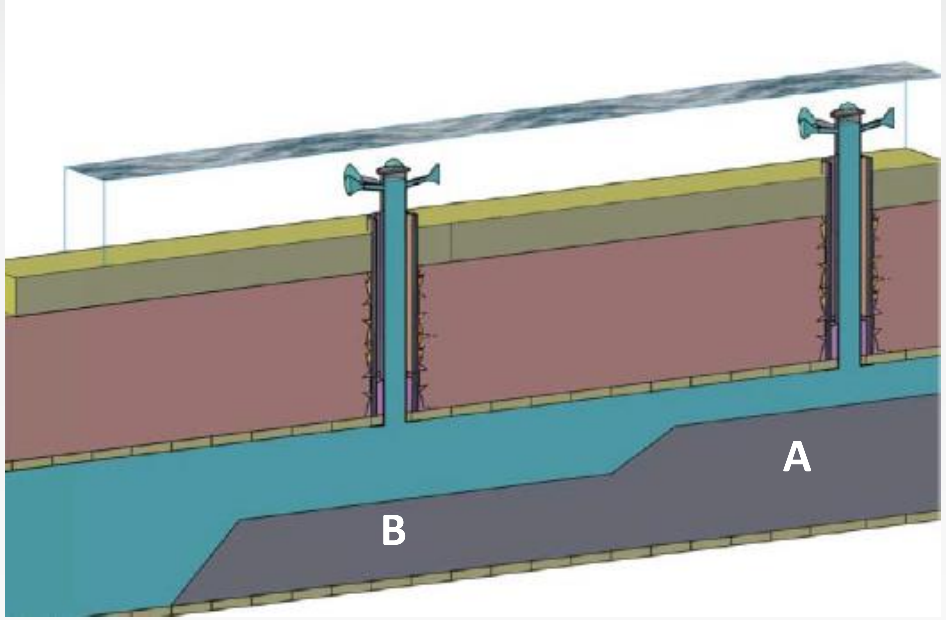
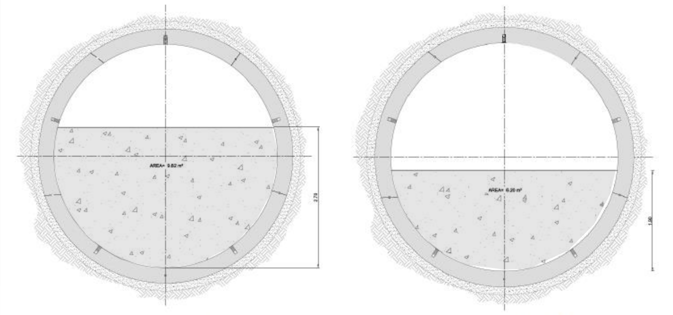


Figura 13: Perfil resultante de velocidades (DN variable – Q=16.20m^3/s)



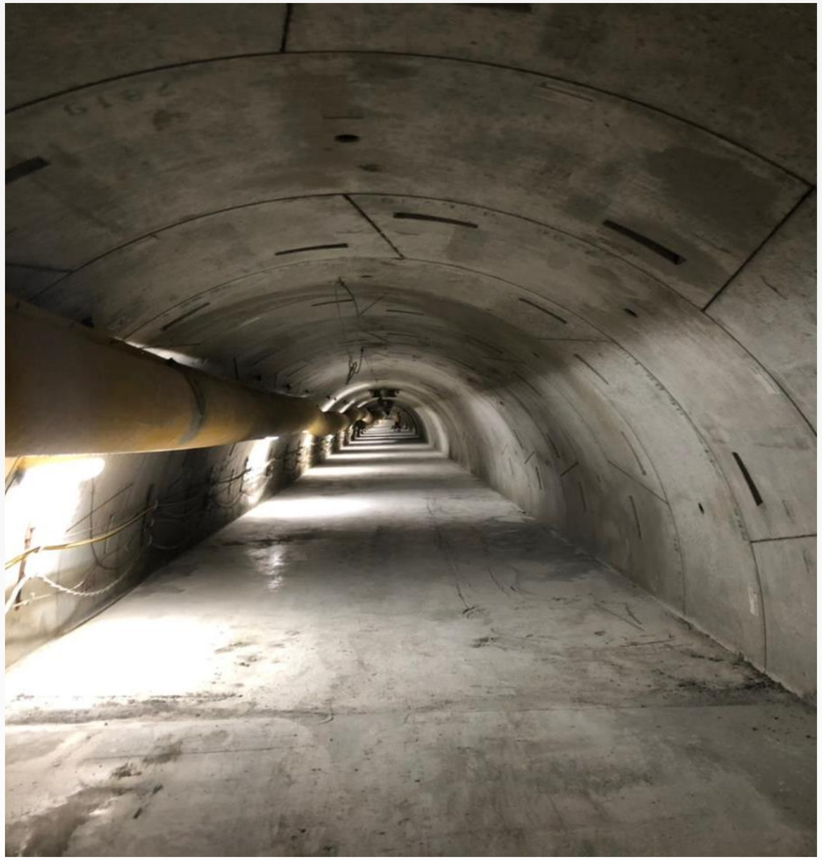


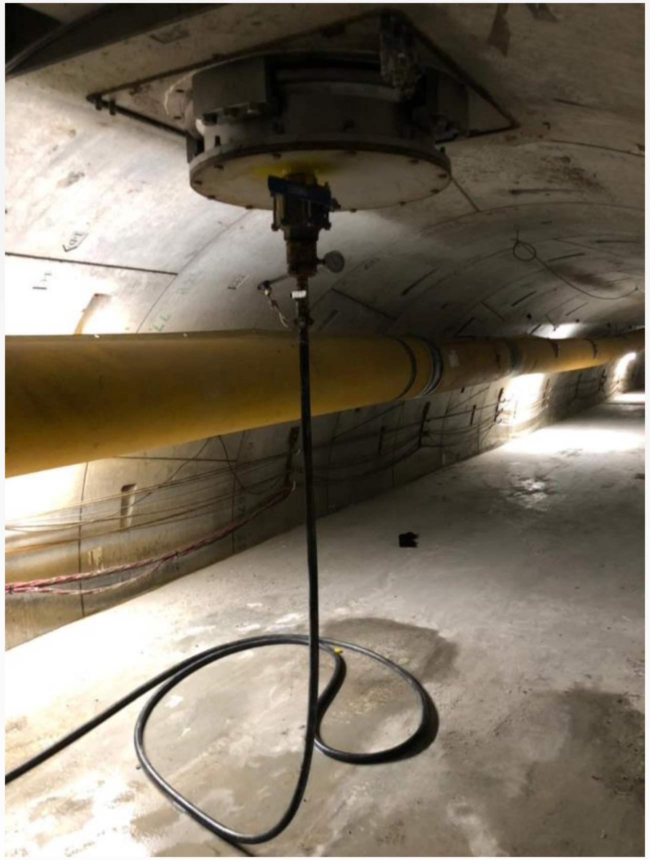
Sección Tipo A

Sección Tipo B

Sección	Largo	Volumen
Tipo A	363 m	3492 m3
Tipo B	600 m	3720 m3

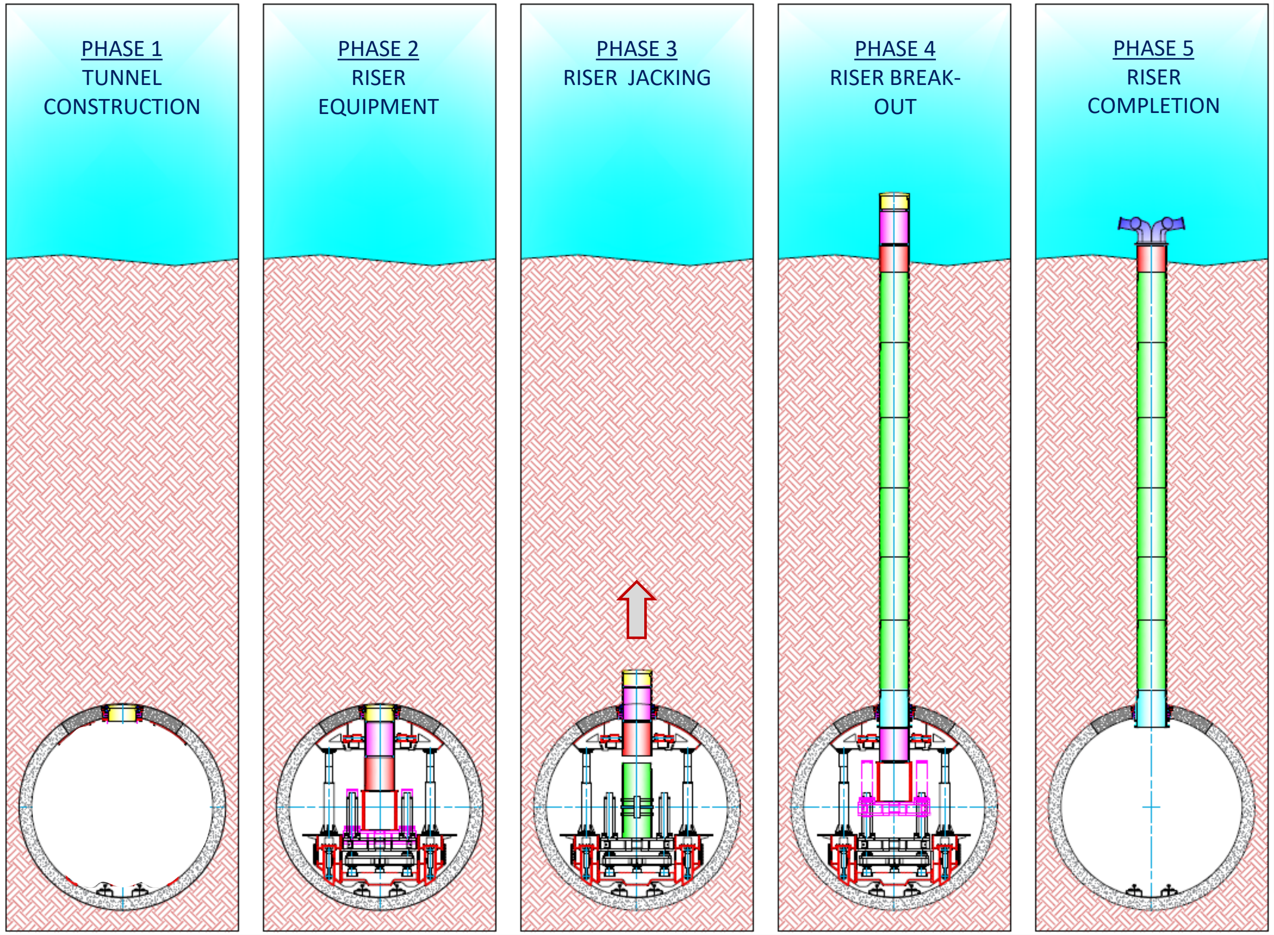
OUTFALL TUNNEL – HYDRAULIC CONCRETE FILL





RISER CONCEPT – INNOVATIVE CONSTRUCTION METHOD

- Bottom-up construction method
- Riser segments jacked upward from inside the tunnel
- Soil excavation by hydro-demolition
- Direct installation of riser's permanent lining
- Underwater break-through
- Fixed permanent Riser-Tunnel connection



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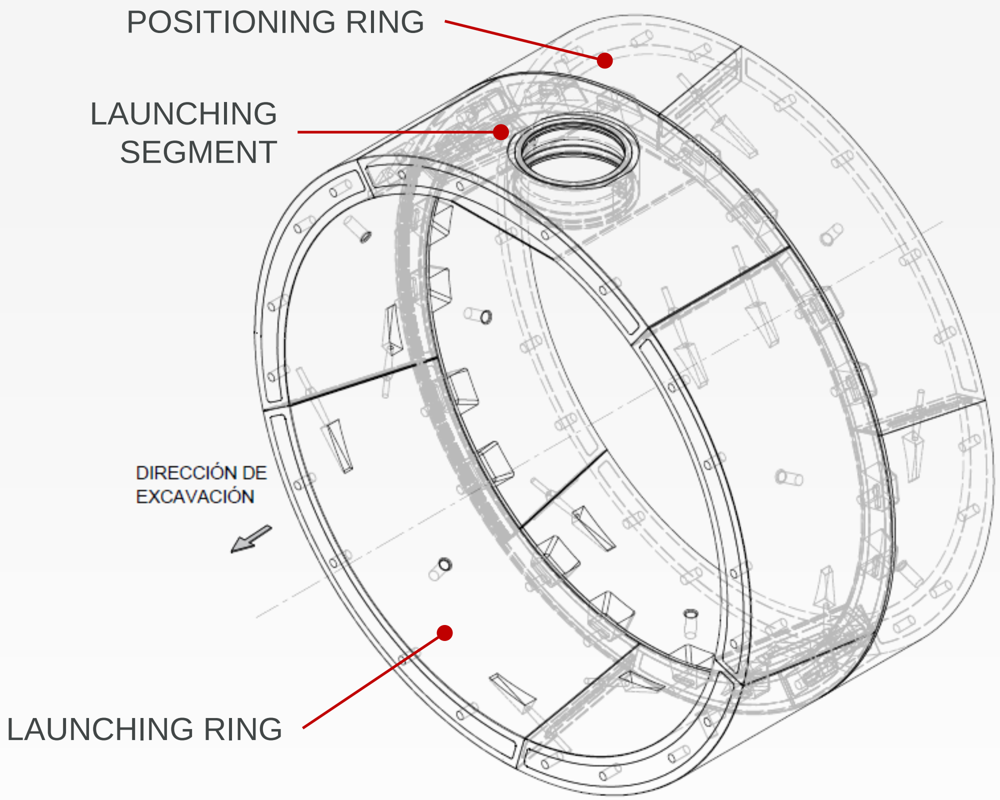
RISER CONCEPT – INNOVATIVE CONSTRUCTION METHOD

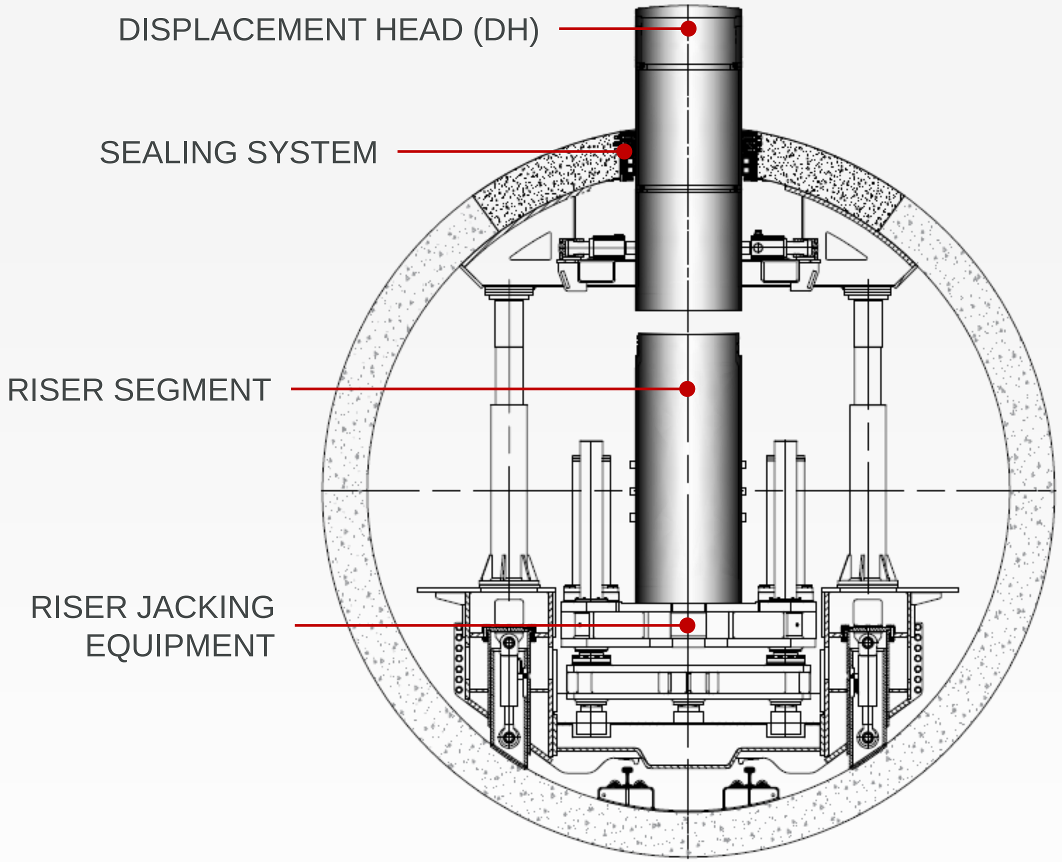
- Installation of Special Segmental rings by TBM
  - ✓ Positioning segmental ring
  - ✓ Launching segmental ring
- TBM disassembly & Riser Equipment assembly
- Jacking of riser segments & material excavation
- Completion of riser
- Removal of DH & installation of Diffuser Head

RISER CONCEPT – MAIN COMPONENTS

TUNNEL CONSTRUCTION



RISER JACKING



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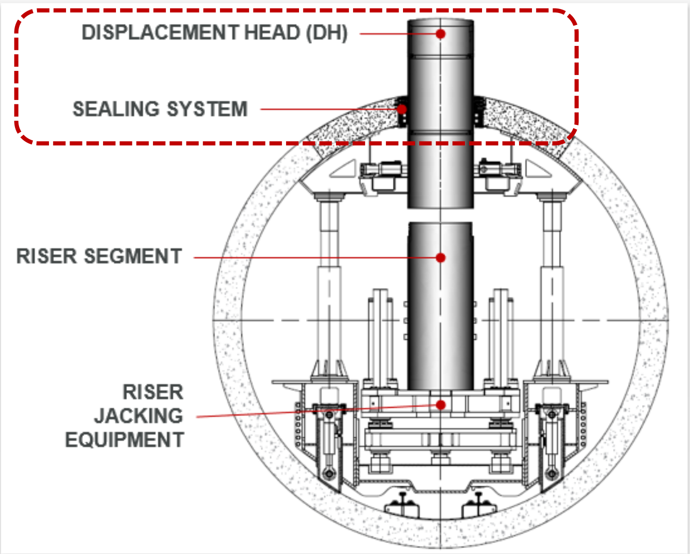
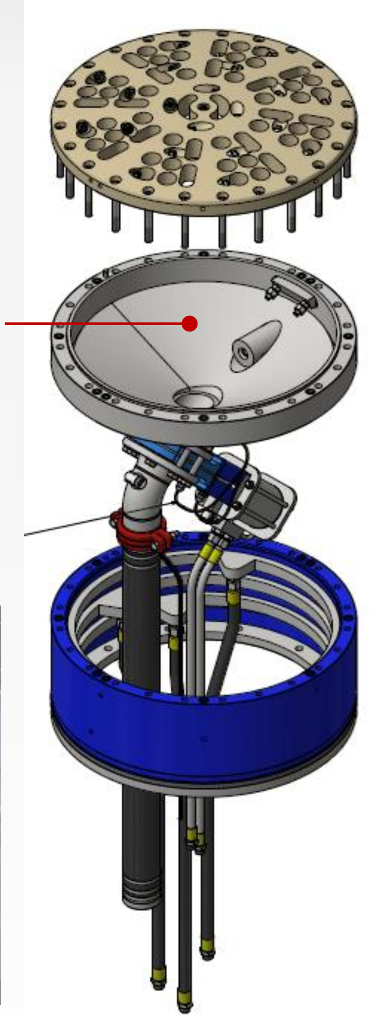
MAIN COMPONENTS – LAUNCHING SEGMENT

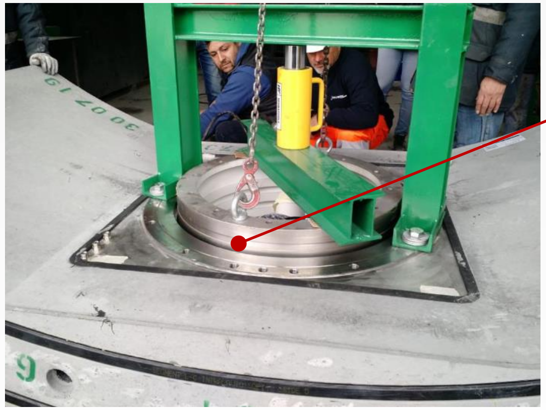


DISPLACEMENT HEAD (DH)

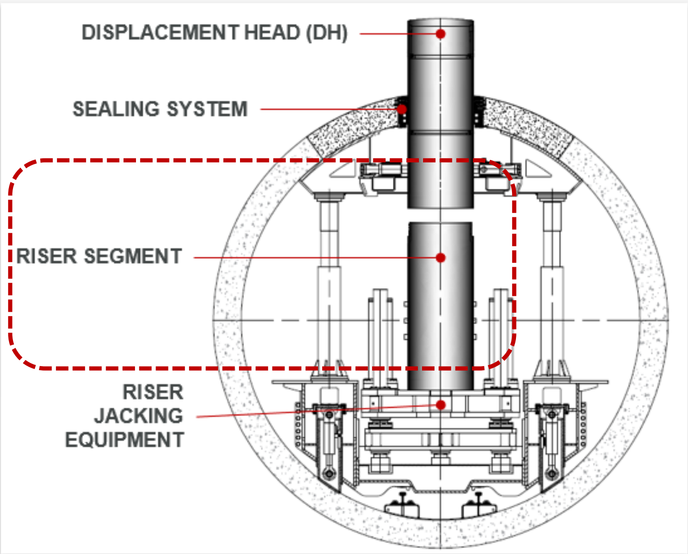


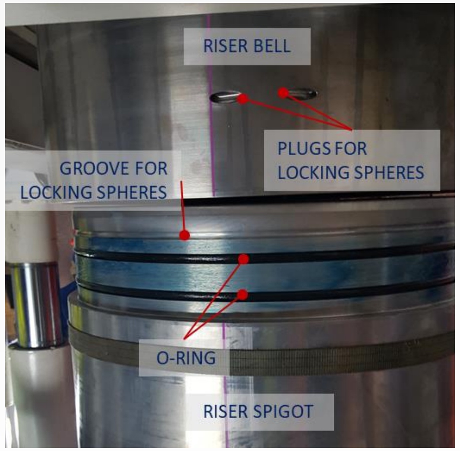
SEALING SYSTEM

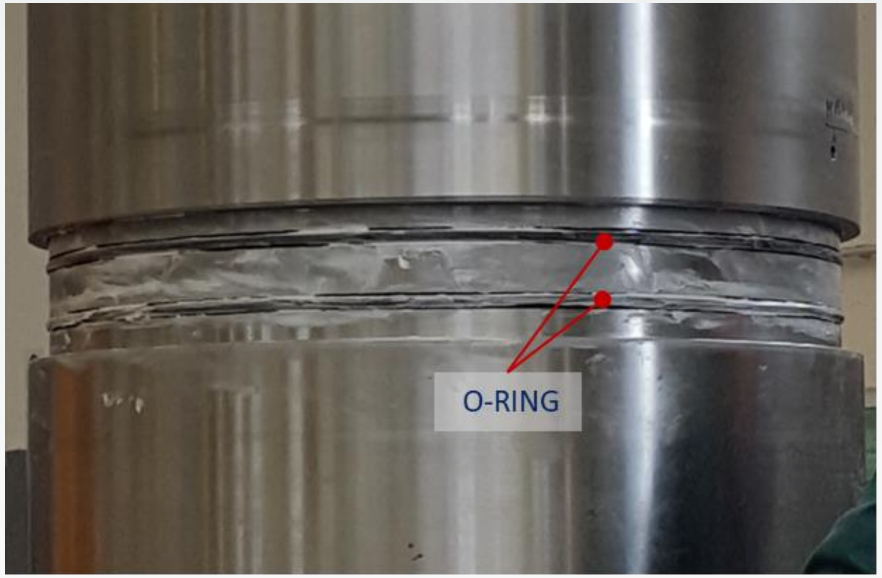
LAUNCHING SEGMENT

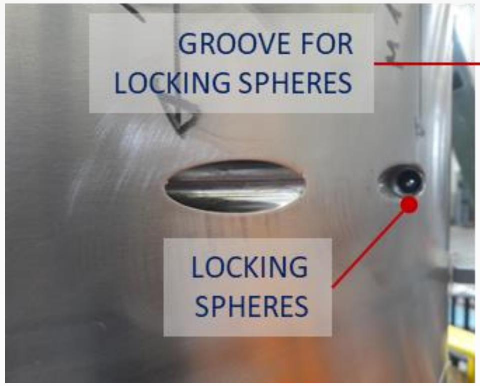


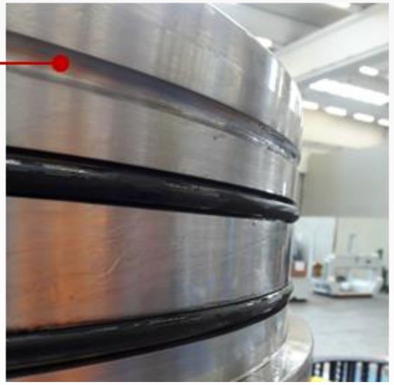
MAIN COMPONENTS – RISER SEGMENTS



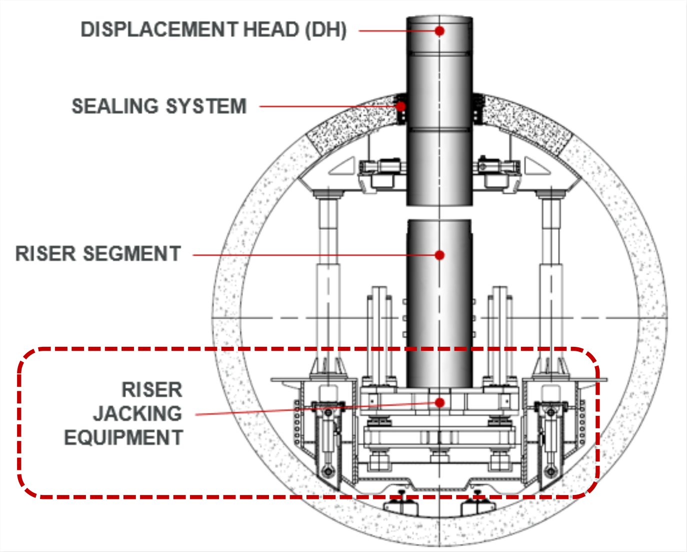


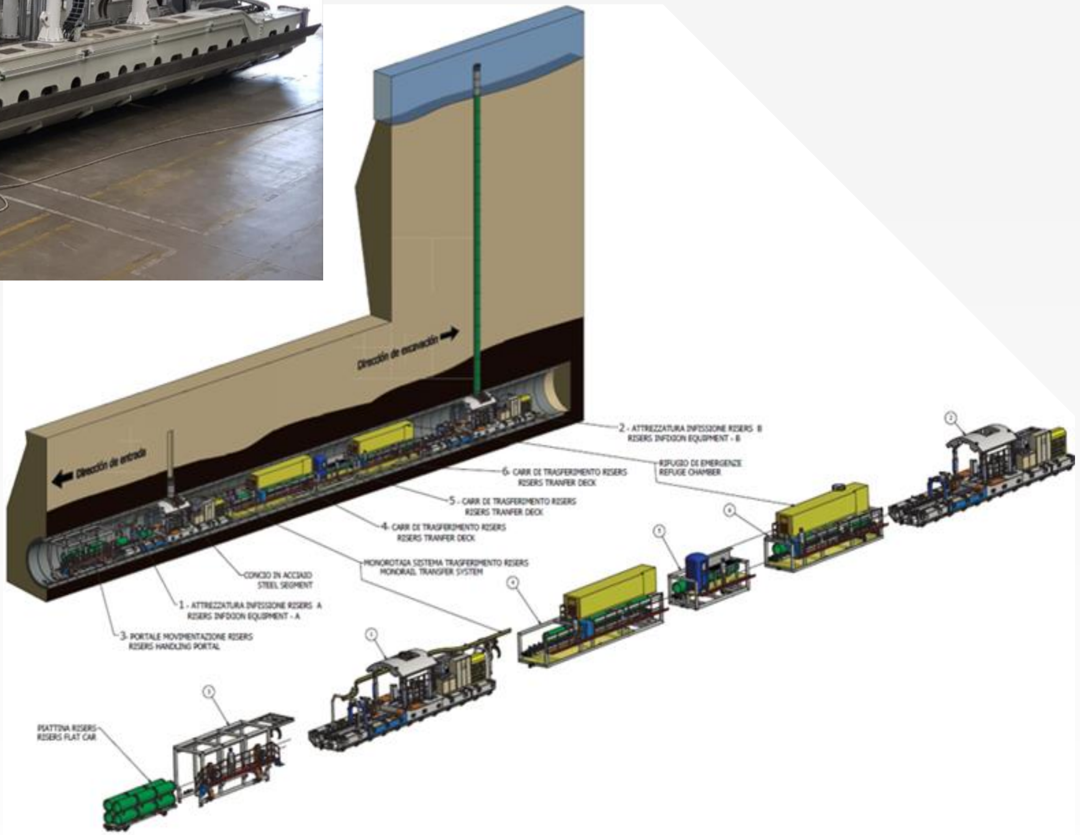






MAIN COMPONENTS – RISER JACKING EQUIPMENT





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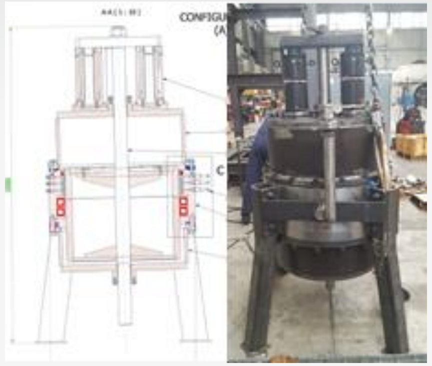
MAIN COMPONENTS – RISER JACKING EQUIPMENT

RISER CONCEPT – PROTOTYPING AND TESTING



SEALING SYSTEM TEST

DEC 2017

RISER SEGMENTS TEST

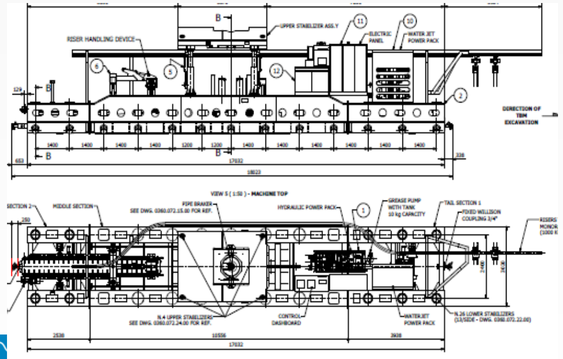
JUL 2018

REAL SIZE TEST

DEC 2018

MAY-SEP 2017

INITIAL DESIGN



APR 2018

DISPLACEMENT HEAD TEST

NOV 2018

EQUIPMENT TESTS

Q3 2020
CONSTRUCTION ACTIVITIES

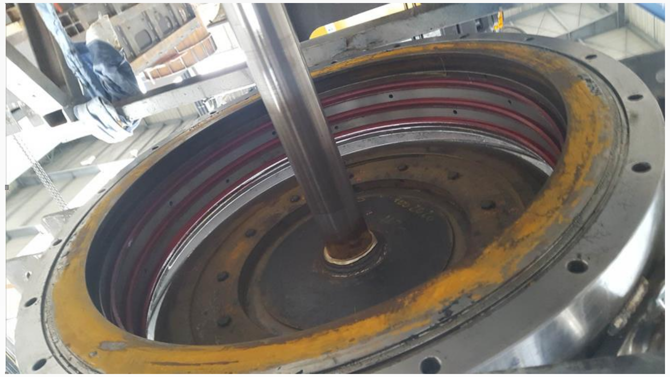
PROTOTYPING AND TESTING – SEALING SYSTEM TESTS

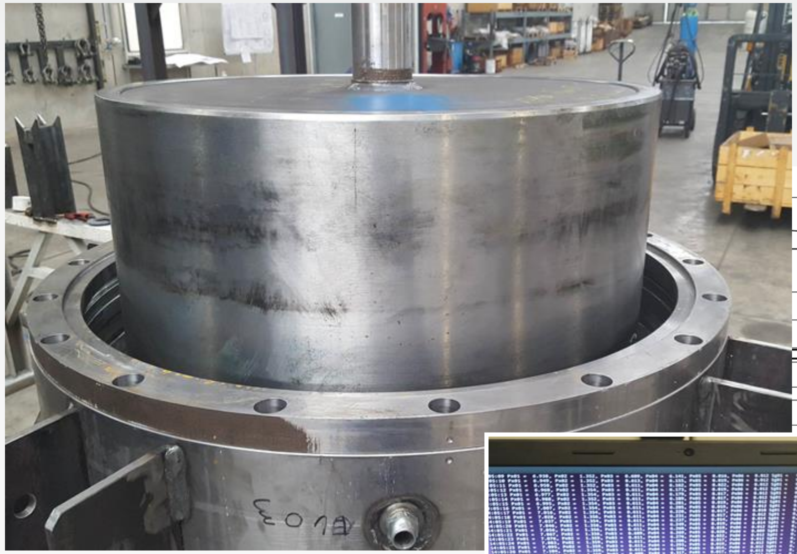
TEST OBJECTIVES

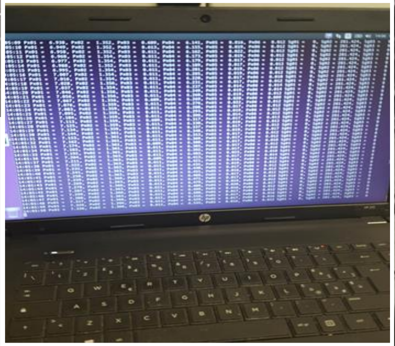
- ✓ Verify tolerances ($D_{ext} \pm 0{,}5mm$)
- ✓ Verify maximum inclination
- ✓ Verify joint geometry

TEST CONFIGURATION

- ✓ Inclined riser (1°)
- ✓ Eccentric riser (ecc. = 4mm)







TEST PHASES

- ✓ Dimensional verification
- ✓ Static test on multi-lip gasket (6bar; 24hrs)
- ✓ Dynamic test on multi-lip gasket (6bar; 120 cycles)
- ✓ Static test on emergency inflatable gasket (6 bar; 12hrs)

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PROTOTYPING AND TESTING – DISPLACEMENT HEAD TESTS

TEST OBJECTIVES

- ✓ Measure jacking force & validate estimation method
- ✓ Verify excavation method and soil removal
- ✓ Optimization of DH & hydro-demolition nozzles

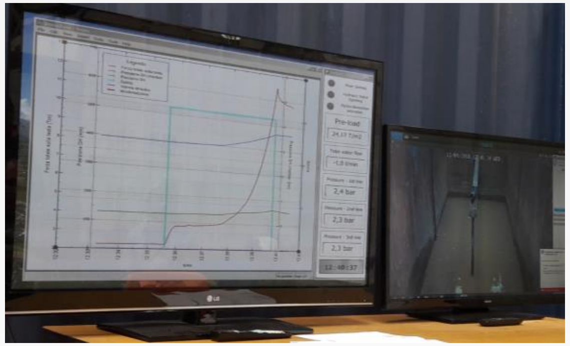
SIMULATED CONDITIONS

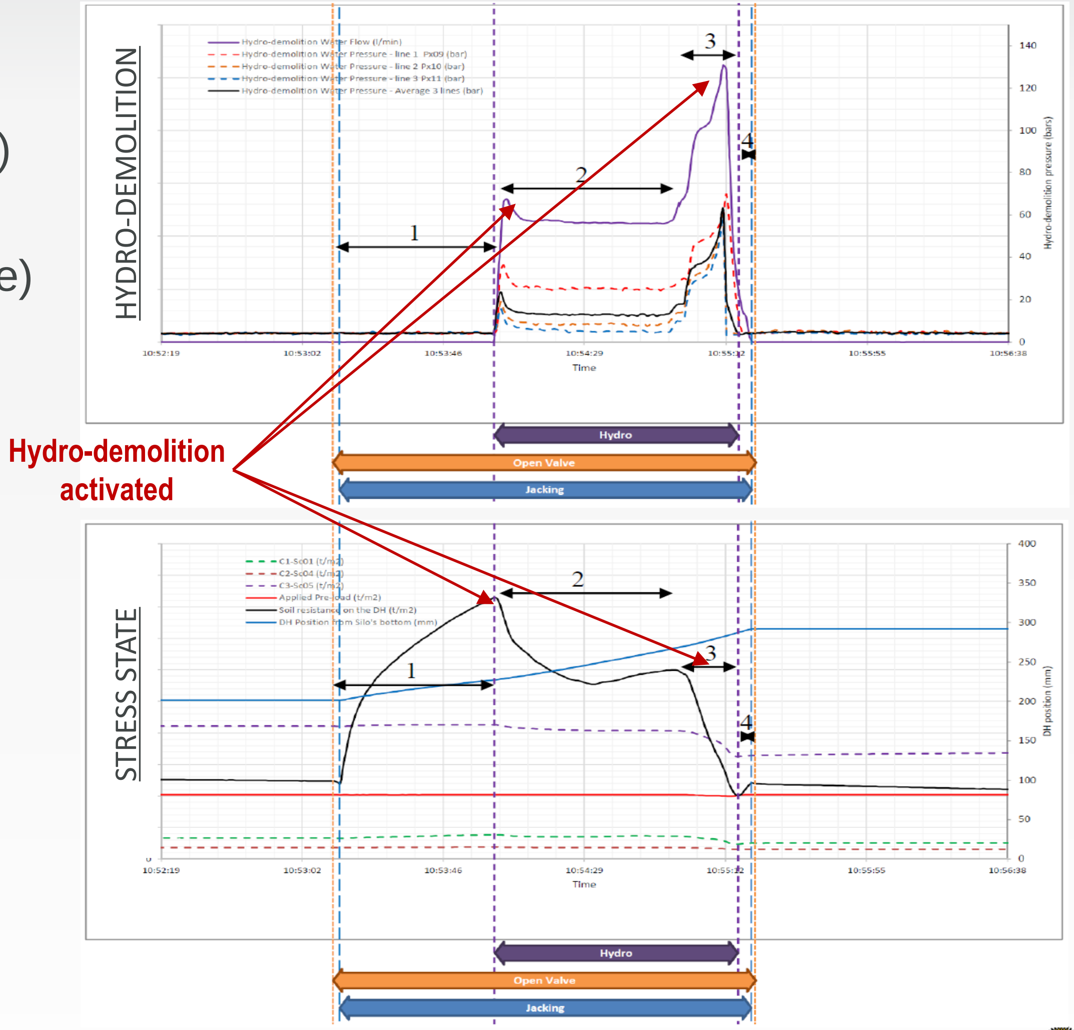
- ✓ Geotechnical conditions
  - *Soil classification*
  - *Compaction*
  - *Saturation*
- ✓ Loading conditions
  - *Stress state*
  - *Hydraulic gradient*
- ✓ Operational sequence
  - *Open mode*
  - *Close mode*

PROTOTYPING AND TESTING – DISPLACEMENT HEAD TESTS

REAL TIME VISUALIZATION OF TEST DATA

- ✓ Forces (jacking force, DH tip resistance, applied load)
- ✓ Hydro-demolition parameters (flow and pressure)
- ✓ Geotechnical parameters (stresses and pore pressure)





TEST OUTCOMES

- ✓ Representative test conditions were confirmed
- ✓ Hydro-demolition efficiency higher than targeted
- ✓ Verified soil excavation and evacuation from DH
- ✓ Validation of jacking force estimation method

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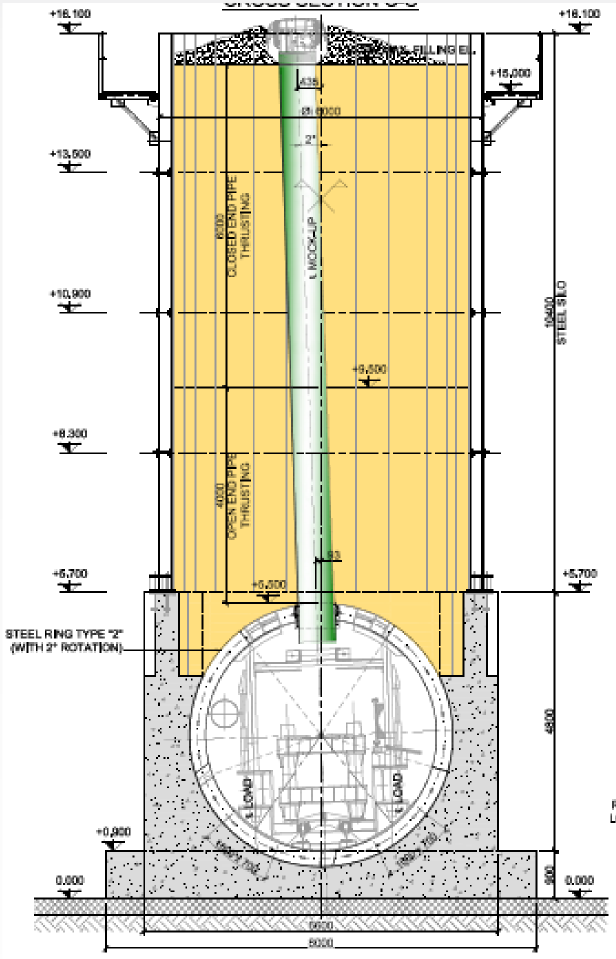
PROTOTYPING AND TESTING – REAL SIZE TESTS

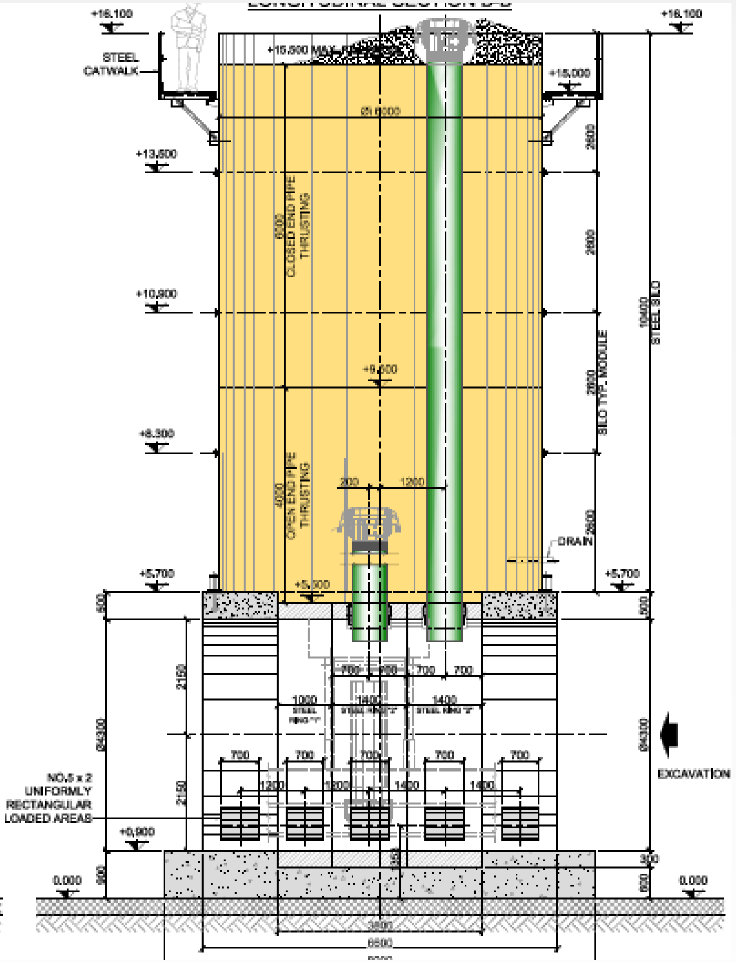
TESTED COMPONETS

- ✓ Riser Segments
  - ➢ *Segment assembly*
  - ➢ *Riser verticality*
  - ➢ *Joint capacity and functionality*
- ✓ Displacement Head
  - ➢ *Stress state*
  - ➢ *Efficiency of hydro-demolition*
  - ➢ *Soil discharge valve*
- ✓ Jacking Equipment
  - ➢ *Sufficient jacking force*
  - ➢ *Load distribution system*
  - ➢ *Operation sequences*

RISER #1: INCLINED



RISER #2: VERTICAL



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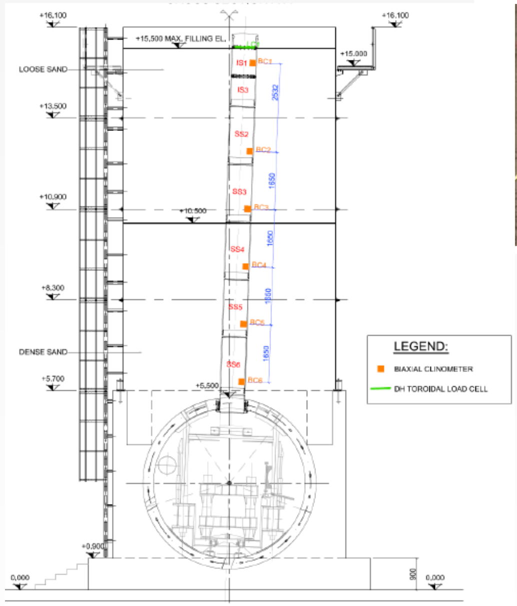
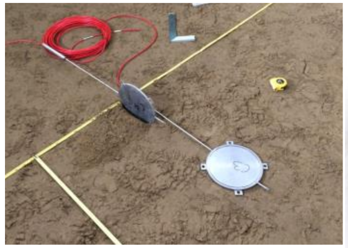
PROTOTYPING AND TESTING – REAL SIZE TESTS

MONITORING SYSTEMS

- ✓ Forces (jacking force and DH tip resistance)
- ✓ Hydro-demolition (pressure and flow)
- ✓ Forces transferred to tunnel (load distribution)
- ✓ Riser inclination
- ✓ Stress state in soil

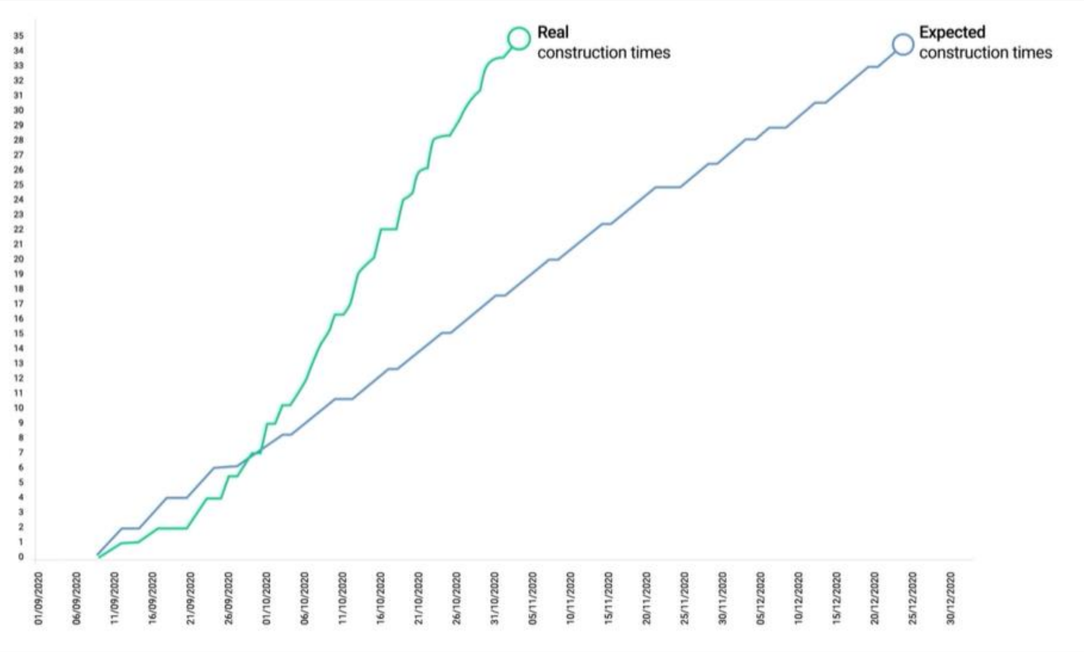


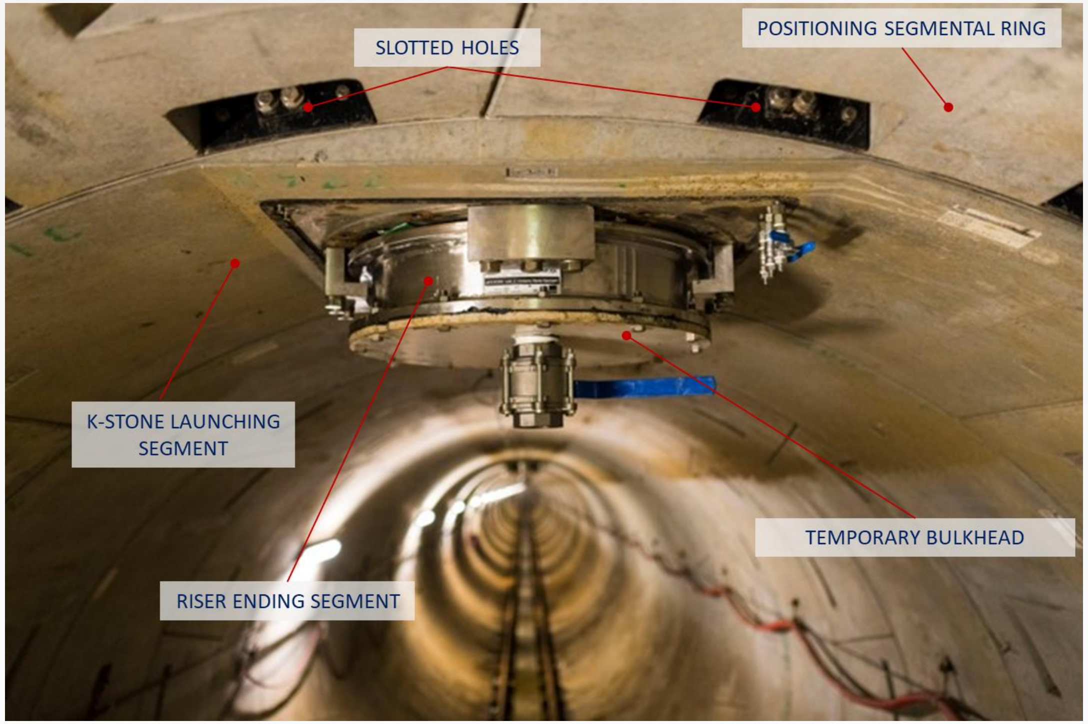


RISER CONCEPT – EXECUTION OF RISERS (RIACHUELO LOT3)

CONSTRUCTION PHASE

- ✓ N.34 risers = **1km of pipes** installed in **50 days**
- ✓ Less than **50% of duration** initially foreseen
- ✓ Highest production rate **6 risers** in **1 week**
- ✓ Excellent outcomes in terms of **safety** and **quality**





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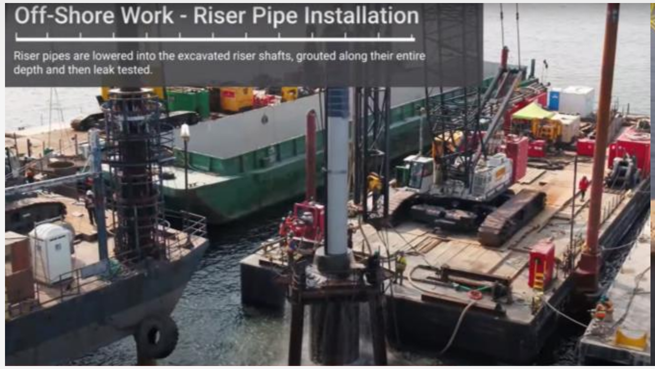
CONVENTIONAL METHODS – ASHBRIDGES OUTFALL (CANADA)

OFFSHORE WORKS

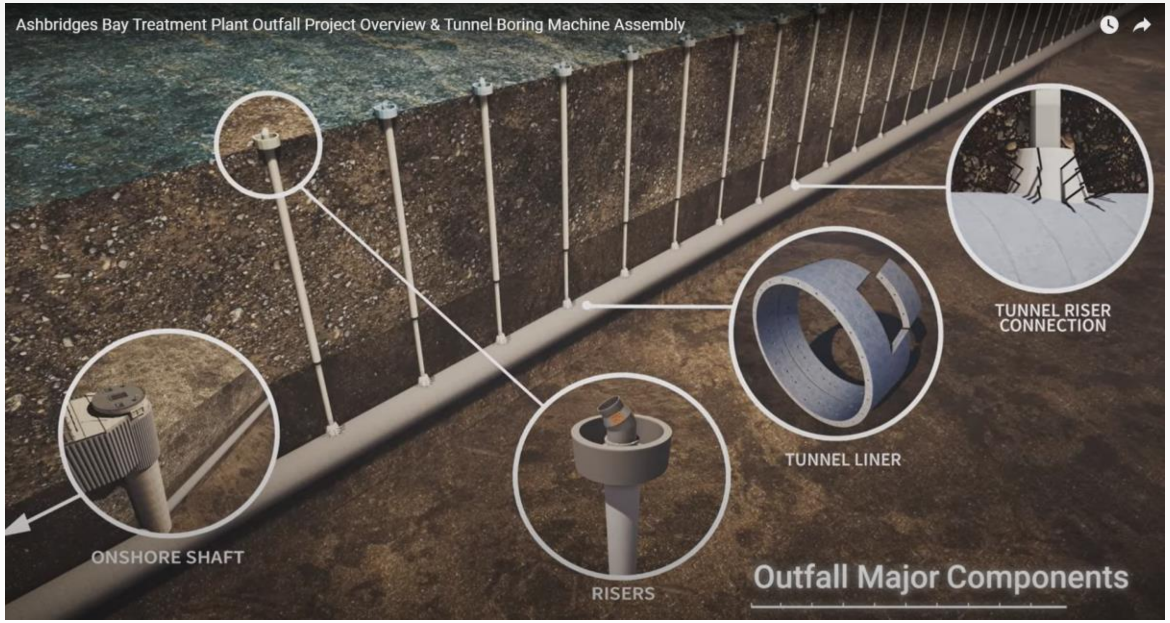
- ✓ Drilling and pipe Jacking installation
- ✓ Annular grout around the pipe

Works restricted during winter season (Nov-Apr) due to weather conditions in the lake



UNDERGROUND WORKS

- ✓ Probe holes drilled from the tunnel
- ✓ Tunnel segment removal/demolition
- ✓ Excavation of riser connection and installation of rock supports
- ✓ Riser connection concreting and repair works

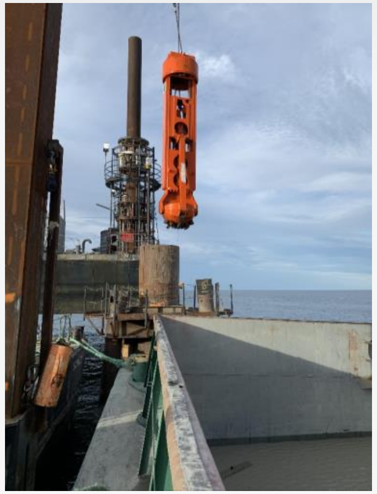


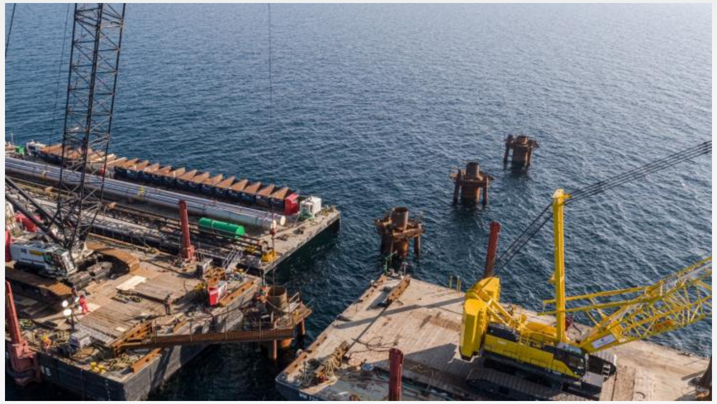
Source: https://www.youtube.com/watch?v=MyqnojlwMP0

CONVENTIONAL METHODS – ASHBRIDGES OUTFALL (CANADA)

MAIN CHALLENGES

- ✓ Off-Shore Work cannot be performed during winter season (November to April) due to weather conditions in the lake.
- ✓ Contractor experienced downtime due to abnormal weather/marine conditions (wave height, wind speeds, etc). Mitigation measures had to be implemented (i.e. additional shifts, re-sequencing of activities).
- ✓ Major constraint: TBM Mining shall not proceed to within 100m of any riser until the riser has been installed, grouted and tested.
  - Risk of potentially having to halt TBM operations if risers not complete.
  - Contingency plan had to be developed





RISER CONCEPT - COMPARISON WITH CONVENTIONAL METHODS

RISER CONCEPT AS ALTERNATIVE TO CONVENTIONAL METHODS IN ASHBRIDGES OUTFALL

RISER CONNECTION - **CONVENTIONAL METHOD**

Step 1: Saw-cut PCTL segment and excavate to locate SS riser pipe.

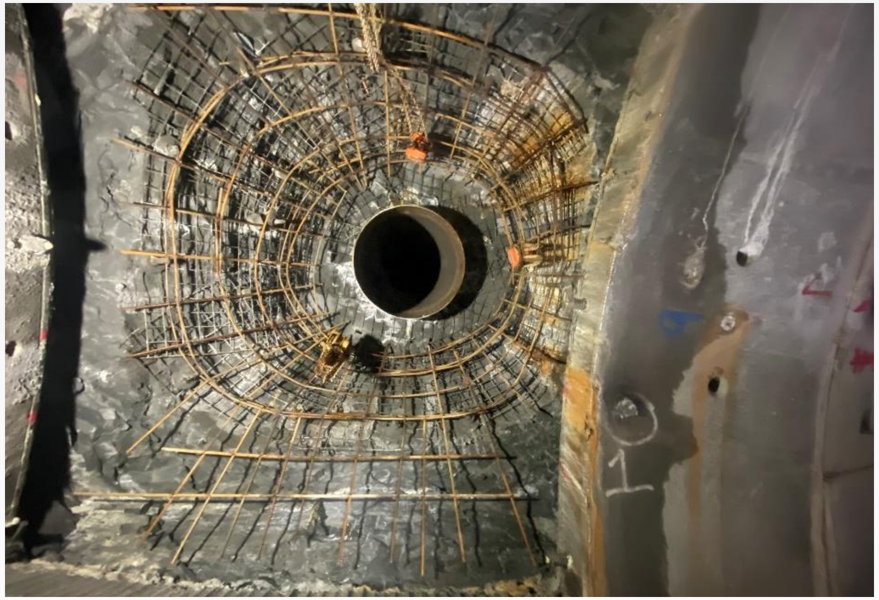
RISER CONNECTION - **RISER CONCEPT**

Step 1: Erection of special segment including provisions for riser bottom-up installation

RISER CONCEPT - COMPARISON WITH CONVENTIONAL METHODS

RISER CONCEPT AS ALTERNATIVE TO CONVENTIONAL METHODS IN ASHBRIDGES OUTFALL

RISER CONNECTION - **CONVENTIONAL METHOD**



Step 2-3-4: Install rock bolts and wire mesh on rock. Install shotcrete. Drain and remove riser bulkead. Place additional rebar.

RISER CONNECTION - **RISER CONCEPT**

Step 2: Mechanized Riser Installation by jacking upward riser segments.

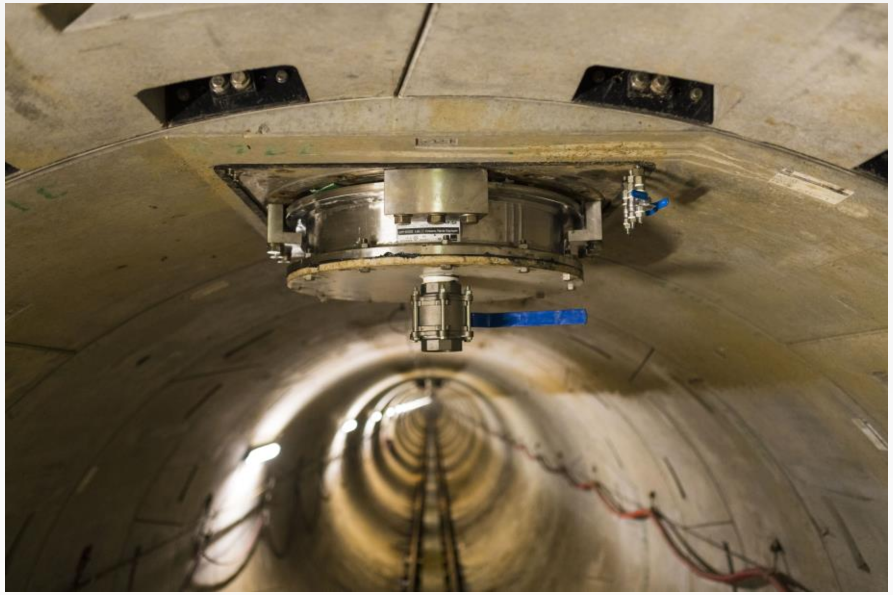
RISER CONCEPT - COMPARISON WITH CONVENTIONAL METHODS

RISER CONCEPT AS ALTERNATIVE TO CONVENTIONAL METHODS IN ASHBRIDGES OUTFALL

RISER CONNECTION - **CONVENTIONAL METHOD**

Step 5-6-7: Place three layers of shotcrete on stay-in-place forms. Concrete injection and cut FRP pipe flush to surface of tunnel.

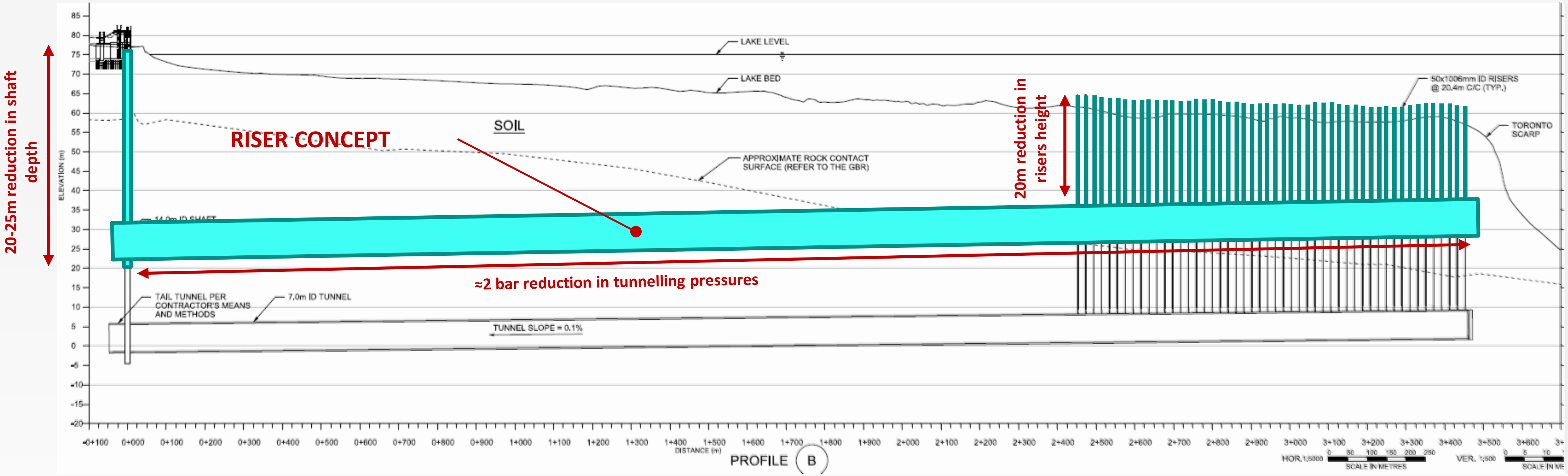
RISER CONNECTION - **RISER CONCEPT**



Step 3: Riser completion including temporary bulkheads, removed prior outfall tunnel flooding

RISER CONCEPT - COMPARISON WITH CONVENTIONAL METHODS

RISER CONCEPT AS ALTERNATIVE TO CONVENTIONAL METHODS IN ASHBRIDGES OUTFALL



ADVANTAGES RISER CONCEPT

- ✓ Enhanced Safety during construction (mechanized solution)
- ✓ Higher quality control and not needs of repair activities
- ✓ Limited environmental impact (maritime works)

ADVANTAGES RISER CONCEPT

- ✓ Construction time reduced and increased schedule reliability
- ✓ Competitive costs and risks mitigation solution
- ✓ Reduced impact with navigation and vessels

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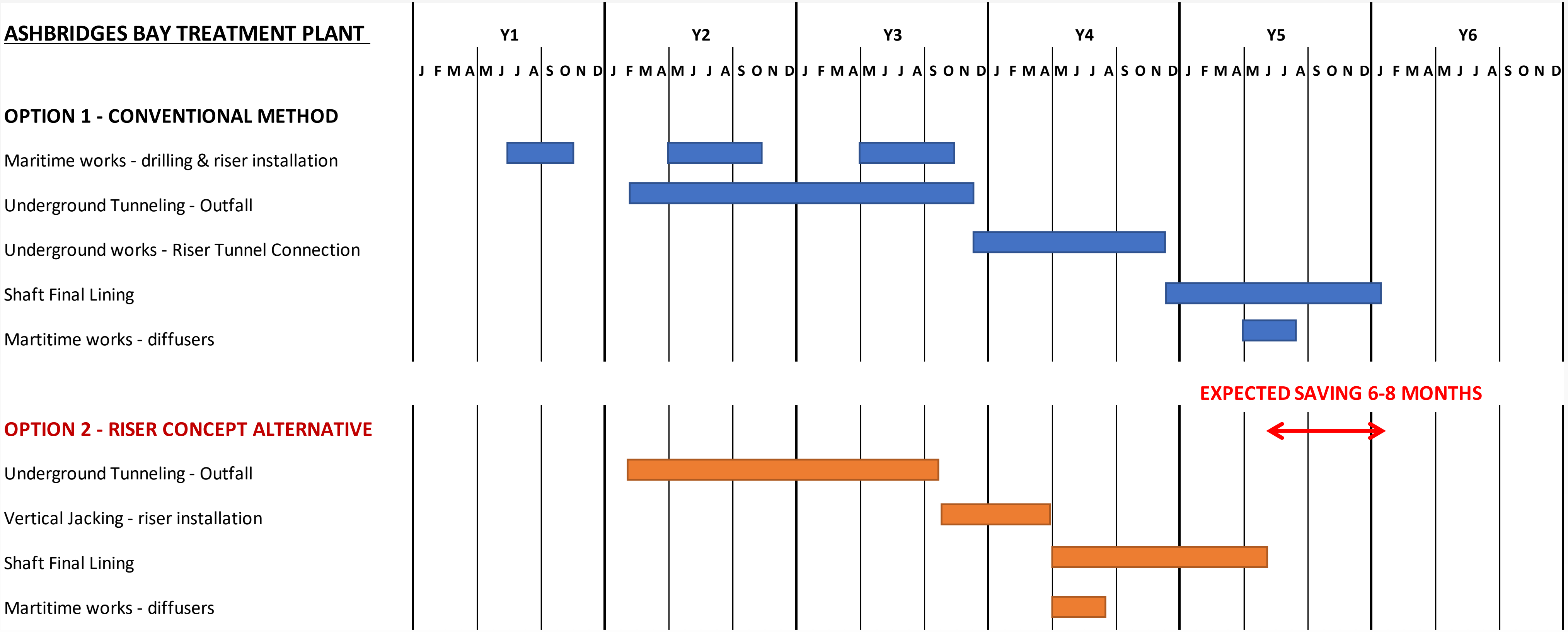
RISER CONCEPT - COMPARISON WITH CONVENTIONAL METHODS

RISER CONCEPT AS ALTERNATIVE TO CONVENTIONAL METHODS IN ASHBRIDGES OUTFALL

TIME SCHEDULE SAVING AND PROGRAM RELIABILITY (Simulation based on estimated production rates)



CONVENTIONAL METHODS – ASHBRIDGES OUTFALL (CANADA)

RISER CONCEPT AS ALTERNATIVE TO CONVENTIONAL METHODS

- ✓ The Riser Concept in Riachuelo Project is **practical** and **advantageous**.
- ✓ It is a **sustainable** construction technique, with an improved worker **safety** and a **reduced** environmental impact.
- ✓ The mechanized method provides **advantages** in terms of safety, quality, time risks mitigation and costs.
- ✓ **Engineering innovation** that changes the way to **construct** risers and represents a **step forward** in the **future of outfall projects**
- ✓ Valuable and proved **alternative** to **conventional construction methods**
- ✓ Technical Innovation of the Year at **ITA Tunnelling Awards 2021**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